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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

JANUARY 1953

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The Journal of

THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

PUBLISHED MONTHLY AT

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All communications for publication in, and advertisements for, the Journal should be addressed to the Editor, Joan Bradbrooke, A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary, A. M. Ballantyne, T.D., B.Sc., Ph.D., A.F.R.Ae.S.

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless stated otherwise.

Royal Aeronautical Society

(Founded 1866)

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The Journal of the Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 57 JANUARY 1953 NUMBER 505

From the President

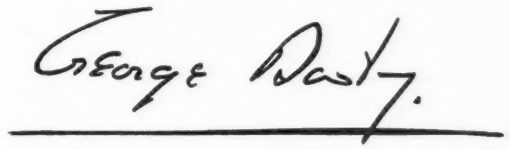
This oncoming year will be a momentous year for the Society, for, not only will our normal activities be exceptional in character, but, with the Anglo-American Aeronautical Conference in September and the 50th Anniversary of the first powered controlled flight by Wilbur Wright in December 1903, we have a full, but intensely interesting programme ahead of us.

A heavy responsibility falls on the Secretary and his Staff; both to them and to those office bearers of the Society to be elected in May, upon whom will rest the task of making the arrangements, we wish every success. To them their appointed duty; to the individual member of the Society the obligation of co-operation and encouragement, for let it be remembered always what is not sown cannot ever be reaped.

It is fitting that in the Second Elizabethan Era, the Society should be courageous in outlook. One indication of the adventurous spirit is the change in JOURNAL format starting with this issue. To this new JOURNAL also we wish every success, with the hope, or rather the expectancy, that it will maintain the reputation built up throughout the past fifty years.

In this great Coronation Year, we ask God's Blessing on our beloved Patron and Queen.

To all our Members at home and overseas I send you greetings from the Society and wish you all a Happy New Year.



President.

NOTICES

Honours Awarded to Members

Wright Brothers Memorial Trophy for 1952

General James H. Doolittle (*Fellow*) has been awarded the Wright Brothers Memorial Trophy. The award marks General Doolittle's "significant public service of enduring value to aviation." He is now assistant on research and development to the Chief of Air Staff, U.S.A.F.

The Bristol and White-Smith Air Transport Medal 1951-52

Mr. N. E. Rowe (*Fellow*, Member of Council) has been awarded The Bristol and White-Smith Air Transport Medal by the Institute of Transport for his paper on "Helicopter Transport in Great Britain."

Members' New Appointments

A. H. A. Bastable (*Associate Fellow*), formerly Technical Sales Engineer of the Hymatic Engineering Co., has been appointed General Manager of the Harper Aircraft Co. Ltd.

F. D. Bush (*Associate*) has recently been appointed Supervisor of Power Plant Production for Bristol Aeroplane Engines Ltd. (Eastern), Montreal.

G. E. Charter (*Associate Fellow*), formerly Liaison Engineer with Teddington Controls Ltd., has been appointed a Project Engineer with de Havilland Propellers Ltd.

A. W. Frazer (*Associate Fellow*) has recently taken up a post as a senior designer with the de Havilland Aircraft Co. Ltd. He was formerly with the Bristol Aeroplane Co. Ltd.

J. D. Hodge (*Graduate*) is taking up employment in the Aerodynamics Section of A. V. Roe (Canada) Ltd. in Toronto.

A. Hucknall (*Graduate*) has recently taken up an appointment as design engineer with Convair Corporation, San Diego.

T. Roberts (*Graduate*), formerly of the Flight Test Department, Saunders-Roe Ltd., has taken up an appointment with A. V. Roe (Canada) Ltd. in Toronto.

D. J. Tyler (*Graduate*) has recently been appointed a Technical Development Assistant with D. Napier & Son Ltd.

Measurement Section of the Institution of Electrical Engineers

Members of the Society are invited to attend a Meeting of the Measurement Section of the Institution of Electrical Engineers which will be held on Tuesday, 17th February 1953, at 5.30 p.m. Tea will be available from 5 p.m.

The papers to be read are:—

I. A. Mossop, B.Sc.(Tech.), and F. D. Gill, B.Sc.(Eng.)—The Measurement of Blade Tip Clearances in Aircraft Turbines by a Method which Measures Minute Changes of Capacitance to Earth at the end of a long Cable.

R. J. Hercock, B.Sc., and D. M. Neale, B.Sc.—Photographic Exposure Timers Providing Compensation for Supply Voltage Variations.

Proofs of the papers will be available about 10 days before the meeting and members should apply direct to the Institution for copies.

Associate Fellowship Examination

Candidates for the May 1953 Associate Fellowship Examination are reminded that all entry forms should be received by the Secretary by the 31st January 1953. Entries from candidates abroad closed on 30th November.

New Performance Data Sheets

A third issue of Performance Data Sheets is now being sent to all holders of complete sets.

The new data sheets deal mainly with the estimation of range, of take-off distance and of landing distance. There are also two further data sheets on instrument corrections and others on the braking thrust and windmilling drag of propellers, which have been prepared with the help of the S.B.A.C. Propeller Panel.

The new price of complete sets, including the latest issue, is £2 11s. 6d. to members of the Society and of the Society of British Aircraft Constructors, and £4 11s. 6d. to non-members. These prices include postage and folder.

Conference on Hydraulic Servo-Mechanisms

Members of the Society are invited to attend an all-day Conference on Hydraulic Servo-Mechanisms arranged by the Hydraulics Group Committee of the Institution of Mechanical Engineers, Storey's Gate, S.W.1, on Friday, 13th February 1953.

The following six papers will be presented:—

Morning Session

(i) An Introduction to Hydraulic Servo-Mechanism Theory, by H. G. Conway and E. G. Collinson.

(ii) Variable Hydraulic Pump Servos and a Method of Impedance Testing, by C. D. Watson.

(iii) Variable Stroke Pumps for Power Transmission—Some Design Considerations, by T. E. Beacham.

Afternoon Session

(i) Hydraulic Servos, by R. Hadekel.

(ii) Industrial Applications of Hydraulic Servos, by T. Brading.

(iii) Some Design Considerations of Jack-Type Hydraulic Servos, by N. F. Harpur.

Evening Session

General discussion on papers presented at the morning and afternoon sessions.

Application forms for tickets may be obtained from this office and must be returned by the 29th January 1953.

Elections

The following is a list of new members and transfers of membership of the Society:—

Associate Fellows

Kenneth Asquith	Arthur Eric Knowler
Frederick Henry Jones (from Associate)	Rudolf Ploszek
	Allan Muir Stewart

Associates

Jack Morgan	Leonard George Sibbick

Graduates

John Francis McCarthy	George Albert Sellars (from Student)

Students

Derek George Burton	Trevor John Ford
David Meredith Edgecombe	Michael John Garms

Companion

Narong Damrongpong

Diary

LONDON

January 27th 1953
GRADUATES' AND STUDENTS' SECTION. A Physical Interpretation of Supersonic Flow. R. Stanton Jones. 4 Hamilton Place, W.1. 7.30 p.m.

January 29th
MAIN LECTURE. Titanium—A Survey. Major P. L. Teed. Institution of Mechanical Engineers, Storey's Gate, S.W.1. 6 p.m. Tea 5.30 p.m.

February 11th
GRADUATES' AND STUDENTS' SECTION. Production of Prototype Aircraft. W. Thorn. 4 Hamilton Place, W.1. 7.30 p.m.

February 12th
SECTION LECTURE. The Application of Integral Construction to Aircraft Design and Its Effect on Production Methods. E. Dixie Keen. 4 Hamilton Place, W.1. 7 p.m.

February 17th
SECTION LECTURE. Recent Developments in Gliding. A. H. Yates. 4 Hamilton Place, W.1. 7 p.m.

February 24th
GRADUATES' AND STUDENTS' SECTION. Viscount Operations. Capt. R. Rymer. 4 Hamilton Place, W.1. 7.30 p.m.

February 26th
MAIN LECTURE. New Materials and Methods for Aircraft Structure. H. J. Pollard. Institution of Mechanical Engineers, Storey's Gate, S.W.1. 6 p.m. Tea 5.30 p.m.

BRANCHES

January 6th 1953
Bristol—Section Lecture. Casting. E. R. Gadd. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

January 7th
Chester—Aircraft Accident Investigation. Air Commodore Sir Vernon Brown, C.B., O.B.E. Grosvenor Hotel. 7.30 p.m.

January 9th
Birmingham—Plastics. A. A. Tomkins. Birmingham Chamber of Commerce. 7.15 p.m.

January 12th
Halton—Branch Night. The Nature, Work and Activities of the Society of Licensed Aircraft Engineers. P. F. Murray. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.
Bristol—Section Lecture. Forgings. J. W. Munday. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

January 14th
Southampton—Annual General Meeting and Film Show. Institute of Education, University of Southampton. 7 p.m.
Weybridge—Reinforced Plastics in the Aircraft Industry. G. C. Hulbert. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.
Brough—Can We Reach Mars? E. Burgess. Lecture Hall, Electricity Showrooms, Ferensway, Hull. 7.30 p.m.

January 15th
Isle of Wight—Modern Aircraft Materials. Dr. H. Sutton. Club House, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.
Portsmouth—Films. Technical School of the de Havilland Aircraft Co. (Portsmouth) Ltd. The Airport, Portsmouth. 6 p.m.

January 19th
Halton—The Art of Detecting and Investigating Faults in the Metallic Parts of the Aeroplane Structure. Dr. J. Fox. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

January 20th
Glasgow—Some Problems and Prospects of Civil Transport. P. G. Masefield. Royal Technical College. 7.30 p.m.
Belfast—British Carriers in Korea. Capt. A. S. Bolt, D.S.O., D.S.C., R.N. New Hall, Kensington Hotel, College Square East, Belfast. 7 p.m.

January 21st
Leicester—Annual General Meeting and Films. The Lecture Theatre, College of Technology, Leicester. 7.15 p.m.
Reading and District—Aircraft Propulsion. A. D. Baxter. The Abbey Gateway, Abbotts Walk. 7.45 p.m.
Coventry—Instrumentation for Testing Aircraft and Aero-Engines. C. N. Jacques. Wine Lodge. 7.30 p.m.
Bristol—Section Lecture. Formings. R. M. Howarth. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

January 26th
Halton—Junior Members Night. Informal talk by Sqdn. Leader A. E. Druett. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.
Henlow—Supersonic Explosions. Flying Officer A. Kirk. 163 Building, R.A.F. Technical College, Henlow. 7.30 p.m.

January 29th
Portsmouth—Production Research in Aircraft. L. E. Bunnett. The de Havilland Aircraft Co. (Portsmouth) Ltd., The Airport, Portsmouth. 6 p.m.

February 2nd
Derby—Colour Films. Presented by William Courtney. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.
Halton—Films. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

February 3rd
Bristol—Film Show. Conference Room, Filton House, Bristol Aeroplane Co. Ltd. 6 p.m.

February 4th
Southampton—Lecture by W. E. W. Petter, C.B.E. Institute of Education, University of Southampton. 7 p.m.
Weybridge—Branch Members. Members' Prize Lecture. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

February 9th
Halton—Powered Flying Controls. Wing Cmdr. D. H. Grundy. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

February 10th
Henlow—Power Plants for High-Speed Aircraft. A. D. Baxter. 163 Building, R.A.F. Technical College, Henlow. 7.30 p.m.

February 11th
Brough—Structural Problems of Advanced Aircraft. H. H. Gardner. Electricity Showrooms, Ferensway, Hull. 7.30 p.m.
Weybridge—Film. Packaged Power. (Northern Aluminium Co. Ltd.) Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

February 12th
Glasgow—The Aiming of Aircraft Weapons. V. B. Smith. Royal Technical College. 7.30 p.m.
Isle of Wight—Aircraft Maintenance. H. Gordon. Club House, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

February 13th
Birmingham—Bird Flight. Captain J. L. Pritchard, C.B.E. Birmingham Chamber of Commerce. 7.15 p.m.
Derby—Provisional date for Dinner-Dance.

February 18th
Bristol—The Impact of the Gas Turbine on Aero-Engine Production Methods. D. A. Fairnie. The Grand Hotel, Bristol. 7.30 p.m.
Reading and District—Rocket Propulsion and Interplanetary Flight. A. V. Cleaver. The Abbey Gateway Room, Abbotts Walk. 7.45 p.m.

Diary Continued

February 20th

Leicester—Viscount Design. D. J. Lambert (Vickers-Armstrongs Ltd.). The Lecture Theatre, Loughborough College. 7.15 p.m.

February 23rd

Halton—Ram Jet Propulsion. Flt. Lt. R. C. Rogers. Branch Hut, R.A.F. Station, Halton. 6.45 p.m.

Henlow—Annual General Meeting. 163 Building, R.A.F. Technical College, Henlow. 7.30 p.m.

February 24th

Belfast—Constructional Trends and their Effect on Airframe Production. R. E. Harvey. New Hall, Kensington Hotel, College Square East, Belfast. 7 p.m.

February 25th

Southampton—Junior Prize Papers. Institute of Education, University of Southampton. 7 p.m.

Weybridge—Brains Trust. Vickers-Armstrongs Ltd., Weybridge Works. 6 p.m.

February 26th

Isle of Wight—Junior Branch Members. Members' Prize Lectures. Clubhouse, Saunders-Roe Sports and Social Club, Church Path, E. Cowes. 6 p.m.

Graduates' and Students' Section

A visit has been arranged to the "Daily Mail" printing works at Northcliffe House, and to the "Daily Herald" printing works at Odhams Press Ltd., on Tuesday, 17th March 1953. Both visits will begin at 9.30 p.m. and will last about two hours. Numbers are limited for each visit and early application should be made to the Honorary Visits Secretary of the Section, C. B. Redgate, *Graduate*, 83 Wandle Road, Morden, Surrey.

Annual Subscriptions

Members are reminded that their annual subscriptions became due on 1st January 1953. The rates are:—

	Home			Abroad		
	£	s.	d.	£	s.	d.
Fellows	5	5	0	4	4	0
Associate Fellows	4	4	0	3	3	0
*Associates	3	3	0	3	3	0
Graduates (aged under 26)	2	2	0	2	2	0
Graduates (aged 26 and over)	2	12	6	2	12	6
Students (aged under 21)	1	1	0	1	1	0
Students (aged 21 and over)	1	11	6	1	11	6
Companions	3	3	0	3	3	0
Founder Members	2	2	0	2	2	0

* Any Associate elected before 1st October 1947 may, if he wishes, elect not to receive the Journal, and in this case his subscription will be reduced by £1 1s. 0d. to £2 2s. 0d.

It will avoid delay and confusion if members, when sending remittances for subscriptions, will state their names clearly and give their addresses and grades of membership. Remittances should be made payable to the Royal Aeronautical Society.

Changes of Address

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address.

When notifying changes please give the following particulars:—

Name (in block letters).
Grade of membership.
New address (in block letters).
Old address.

Changes of address must be received *before the 15th of the month* in order to be effective for the Journal for the following month.

Journal Binding

Self-Binder Cases

Self-Binder cases of the "Easibind" type are available from the offices of the Society. These binders are for members who do not have their Journals permanently bound, or who wish to keep their Journals together during the year for binding later.

These cases will hold 12 Journals which are kept in place by means of flexible steel wires. Journals can be inserted or withdrawn easily without damage, so preserving the contents for permanent binding later. The Journals will open flat at any page.

The binder is strongly made in durable dark blue leather cloth on stiff board covers and has gold lettering on the spine. The year is not blocked on the spine but there is a panel on which members who wish to use the binder as a permanent case can put the date.

The cost is 11s. 6d. each including postage and packing for either the size to fit 1952 and previous Journals, or for the size to fit the Journal from January 1953, which will be increased in size. Orders and remittances should be sent direct to the Secretary at the offices of the Society and it is *important to state whether the old size or new size is required.*

Permanent Binding

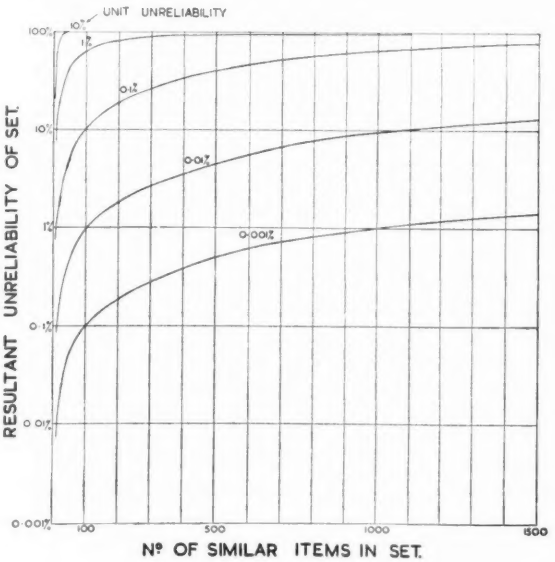
There is no increase in the price of permanent binding of Journals. The prices are:—

1952 Volume (including packing and postage) 16s. 0d.
Previous Volumes (including packing and postage) 18s. 0d.

Journals, *with a note of the name and address of the sender,* should be sent direct to the Lewes Press, Friars Walk, Lewes, Sussex, and the remittance to the Secretary at the offices of the Society.

Correction to December 1952 Journal

In the paper by Group Captain Buxton in the December 1952 Journal, "Problems of Servicing and Reliability," Fig. 1 on page 872 has been found to be incorrect. It should be replaced by the figure shown here.



The Journal of The Royal Aeronautical Society

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

VOLUME 57 JANUARY 1953 NUMBER 505

FOREWORD

by

PETER G. MASEFIELD, M.A., F.R.Ae.S.

Vice-President of the Society and Chairman of the Journal Committee of Council

THIS NEW YEAR issue of the JOURNAL of the Royal Aeronautical Society—its 57th year of publication—marks an important step forward in its history and presentation.

As its readers will have seen, by a decision of the Council the JOURNAL now appears with a larger page form, printed on better paper, in improved type, with modified layout and a new cover.

The objects of these changes are both practical and aesthetic. The larger page will make possible a much more satisfactory presentation of technical papers and will reduce costs because of the smaller ratio of margins to page size, the fact that more can be put on a page and that the same amount of information can be printed in fewer pages.

In addition one type of paper can now be used throughout for both advertisements and text, offering better results from illustrations and a saving in cost because of the avoidance of the necessity to insert special art paper sections. A further point is that the new size will, we feel, make the JOURNAL easier to read and make possible a better layout of reports and articles while cutting down the costs of advertisements through the use of a standard size of blocks made for the aeronautical press generally.

Foremost of the other changes which have been made in the JOURNAL is the treatment of the Notices of the Society. Although included as part of the JOURNAL each month, they are being numbered separately so that they need not be bound in with the JOURNAL at the end of the year. Other changes include summaries, wherever possible, of the reports which are received in the Library each month, and signed reviews, which the Journal Committee believe will be of increased value to members.

We hope that the Industry, the Research Establishments and the Universities will contribute to the Technical Notes. The Society intends to provide in that Section the opportunity for research workers to set on record brief reports or interim reports on items which either do not justify fuller treatment, or where final results will not be known for some time. We believe that such Technical Notes will be of interest and value to others working on similar lines and will stimulate also, written discussion. Naturally, publication of much of the work being done at present may be restricted by security but the Journal Committee and the Editor believe that there is much which can be published, and discussed, in this Section of the new JOURNAL.

There will be some, of course, who will bemoan the loss of the old JOURNAL and regret the change to the new. We are a conservative race and we hate change. There will be some who say that the old JOURNAL was a more convenient size for book shelves.

I am confident, however, that after a few months of experience with the new format, few people will continue to hanker after the old. One thing I do want to make clear is that in developing the JOURNAL of the Society there is no thought or intention of entering in any way the field of the technical aeronautical press, which use pages of a similar size. The job of the Society's JOURNAL is to serve members, to report the proceedings of the Society, its lectures and its discussions and to offer a field for scientific and technical papers and notes. That is a task which the JOURNAL has been doing for 56 years. In the new form it will be able to do the job still better than in the past.

It is not possible to include papers of interest to all members each month but it is hoped to cover all sections of aeronautics as often as possible and this first number covers a fairly wide range. The paper on noise reduction by means of a running-up pen is of topical interest in view of the publicity given to the pen—or wall—now being built at London Airport as a result of the experiments described in this paper. Another topical subject is dealt with by a well-known author in a way which is sure to create interest, if not controversy.

For students or less specialised members, there is an introductory paper on rockets by three Student members, and a short paper by a well-known pilot on test pilot training. Another paper of some importance describes a device which, according to one authority, may become in due course, an important piece of equipment in every firm in the Industry—certainly it will be of interest to all concerned with flutter calculations.

Of the Technical Notes, one describes interesting results from a method adopted by Armstrong Whitworth in obtaining some information for one of the Society's Data Sheet Committees; a second gives a method of dealing with strain measurements and an idea of the precautions necessary to obtain the right answer using such a method. The third suggests a method for dealing with stiffness problems for thin-walled tubes.

Comments on the JOURNAL in its new form and suggestions for future numbers will be welcomed and given every consideration by the Editor.

I want here to pay a tribute to the Editor of the JOURNAL, Mrs. Joan Bradbrooke. She took over the Editorship from Captain J. Laurence Pritchard in 1946 and much of the success of the old JOURNAL in recent years and much of the imaginative thinking behind the new form, is a result of her work. The Society is well served by its staff in this as in other directions.

A few words may be of interest here about the past history of the JOURNAL. It was founded in January 1897 as a Quarterly to succeed the annual reports of the Society, the first of which was published in 1867.

The JOURNAL became a monthly product in 1918 and has remained since then at approximately the same size.

At the present time about 9,000 copies are being printed every month, of which some 7,900 go to members of the Society. In addition there are more than 900 subscriptions to the JOURNAL from 45 countries abroad. I believe that I am not overstating the situation when I say that the JOURNAL enjoys an extremely high reputation among aeronautical authorities all over the World.

During its 56 years of existence, the JOURNAL has contained papers contributed by many of the most famous names in Aviation, including the Wright Brothers, Lilienthal, Parsons, Pilcher, Holt-Thomas, Lanchester, Prandtl and practically a complete collection of those pioneers who are still, happily, with us.

The JOURNAL has been printed by the same firm for the past 30 years and some of the men concerned in its preparation have, in fact, grown up with it. But for its present firm of printers the JOURNAL might not have survived the first six years after the 1914/18 War. They have taken a keen interest and pride in the Society's publications and much has been owed to them.

For the future, the Editor and the Journal Committee have plans for developing the services of the JOURNAL to members in various directions without in any way invading the territory of the established aeronautical press. Much of the future will, however, be up to the members of the Society who can improve the JOURNAL by contributing papers and suggestions to the Editor.

I trust that in its new form the JOURNAL will go forward to enhance the reputation it has built up throughout the World during the first 56 years of its life.

Acoustic Screening by an Experimental Running-up Pen

by

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SUMMARY:—In 1951 the Ministry of Civil Aviation made an investigation into the acoustic screening offered by the use of a running-up pen. Tests at London Airport in which a Viking was run up behind an experimental wall constructed of corrugated cement asbestos sheeting fixed to a scaffolding of steel tubing showed that a reduction of some 25 phons could be obtained throughout most of the geometrical shadow of the wall and over a range of distances probably exceeding one mile. Unexpected acoustic characteristics of the experimental wall precluded the collection of the full design data on running-up pens that were sought, but did not detract from the efficacy that was demonstrated. Auxiliary tests suggested that little noise abatement can be achieved by the use of trees or buildings. A prototype running-up pen is now being built at London Airport to find what operational problems are associated with the use of running-up pens and, if possible, the design data still required.

1. Introduction

Among the noise problems confronting airport authorities is that caused by the running-up on the ground of the engines of an aeroplane. A proportion of this running-up occurs at the end of a runway immediately before take-off when the aeroplane is more or less mobile and it is difficult to see what remedial action is possible. The rest, however, occurs during maintenance operations when the aeroplane is stationary and some remedial action is, on the face of things, not impossible. The Ministry of Civil Aviation Noise Abatement Committee, after examining various methods which seemed feasible, concluded that a running-up pen appeared to be the most promising method and warranted full-scale experimental work. An investigation was put in hand to find by how much a pen would reduce the noise and over what areas. This investigation was primarily an acoustic one and it was accepted that, should the results be satisfactory from the point of view of noise abatement, there might still be operational problems which might not be easy to solve.

This paper describes the work that was done by a field party drawn from the Ministry of Civil Aviation and under the direction of the author.

2. The Design of the Investigation

When the investigation started it was by no means certain that a pen was going to give an adequate abatement of noise. In essence, the task was to determine by how much, and for how far, an obstacle would reduce the sound coming from an aeroplane on the ground or, in other words, to explore the acoustic shadow cast by an obstacle. Common experience suggested that the best results would be obtained by having the aeroplane as close to the obstacle as possible and a pen was thought of as consisting of a straight front wall and side walls extending backwards. The literature on the subject gave no indication as to the quantitative effectiveness of such an arrangement and a theoretical examination promised less reliable conclusions than a practical one.

In qualitative terms, it appeared doubtful whether the effectiveness of a pen would extend beyond relatively short distances, since acoustic shadows were thought to be much less pronounced than optical shadows. It was not only that a solid barrier, which is impenetrable by light, may be far from impenetrable by sound. Beyond the barrier, there are contributions of energy caused by diffraction at the edges of the barrier and by scattering in the non-homogeneous atmosphere. Thus, at any distance from a barrier, there are three contributions: from transmission, from diffraction, and from scattering. With light, these contributions are all small and an obstacle therefore gives a fairly well defined shadow. With sound, the contributions are all appreciable and an obstacle does not give a clear shadow; in fact, it may give no noticeable shadow at all.

At a given point within the geometrical shadow, the screening effect may be defined as the ratio between the sound pressure level at the point were there no obstacle and the summed effect of the transmitted sound, the diffracted sound, and the scattered sound. In subjective terms it will be the difference between the corresponding loudness levels. When the diffracted sound and the scattered sound intrude sufficiently to make up for the reduction on transmission through the barrier, there is no screening effect. The amount of diffracted and scattered sound depends on the geometry of the source of sound, the barrier, and the reception point and is quite independent of the physical nature of the barrier. It was argued that the screening effect would be greatest near a running-up pen but, at some distance away, it

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would have fallen to zero and this distance would be largely independent of the type of pen built. The aim of the investigation was to determine this distance. It was found, in the event, that these starting premises were too pessimistic.

The way in which the investigation should be planned now seemed clear. A running-up pen was to be simulated by an experimental wall which would be erected in stages, at each stage representing a different size of pen. The wall was to be constructed so that immediately in front of it there would be a measurable reduction of sound level against which the sound level reductions farther away could be compared, and the screening effect and its variation with distance so determined. Any controllable source of sound, placed behind the wall would have served the purpose, but the most appropriate was an aeroplane engine.

It was decided that the investigation should be based at London Airport, but before the investigation could start there were further points to be considered. During the investigation there were going to be variables which either had to be controlled, or proper allowances made for their departure from some standard set of conditions. It was essential that the source should give a constant output and preliminary tests showed that reliance could be placed on the constancy of the sound output of a given aeroplane engine. Another possible variable was the terrain over which the sound generated by the aeroplane engine was to be propagated. This was overcome by making the tests on a non-operational runway of just under 3,000 ft. of level, uninterrupted concrete. An additional advantage of this site was the absence of any buildings which might have caused reflections. On the other hand, measurements were limited to the line of the runway, although in two instances, which will be mentioned later, measurements were made off the line of the runway.

The most important variable was the weather. The effect of the temperature and humidity of the atmosphere on the propagation of sound has been known for many years and appropriate corrections could be made[1]. This left the effect of wind. Qualitatively it was a matter of common experience that sound travels farther downwind but no records of quantitative measurements could be found. It followed that either the tests would have to be confined to dead calm conditions, an impracticable limitation, or else the variation of sound transmission with wind conditions had to be explored. A study was therefore made in a preliminary investigation, and the results, which are being reported elsewhere, established empirical corrections in terms of the vector wind (*i.e.* the wind component along the line of sound measurements) that could be applied with reasonable confidence over the ranges of distance covered in the investigation.

3. Equipment and Facilities

3.1. THE TEST AEROPLANE

A Viking 1A aircraft was lent by the Ministry of Supply for the investigation. It was fitted with two Bristol Hercules 630 14-cylinder engines, with exhaust systems consisting of collector rings connected to manifolds discharging under the mainplanes. The engines drove, through a reduction gear of ratio 0·444 : 1, four-bladed de Havilland metal propellers 13·25 ft. in diameter.

3.2. THE EQUIPMENT USED FOR SOUND MEASUREMENTS

The sound measurements were made with the Standard Telephones and Cables Ltd. Objective Noise Meter. This instrument consists of a microphone, a calibrated attenuator, an amplifier of known gain and an output meter indicating approximately the root-mean-square value of a complex waveform. By inserting electrical filters, the sound pressure levels per octave were measured in decibels in each of the eight octaves 37·5-75, 75-150, 150-300, 300-600, 600-1,200, 1,200-2,400, 2,400-4,800 and 4,800-9,600 cycles per second. Selection of each octave is manual, and it was found that, with a little practice, just over half a minute was required to measure the levels in the eight octaves.

Using a method proposed by Beranek[2], the objective measurements were translated into subjective units, each set of eight sound pressure levels in decibels being replaced by a single loudness level in phons. In this way there was some fairing of the experimental points and, at the same time, the results could be digested more easily. It should also be mentioned that the use of loudness levels enables the relative loudness of two sounds to be appreciated, for, if there is a difference of about 9 phons in the loudness levels of two sounds, an average observer will judge one to be half as loud as the other.

The microphone was placed on a tripod so that it stood about 4 ft. above the ground and was surrounded by a wire cage covered with fine muslin to prevent the wind affecting its response.

3.3. COMMUNICATIONS EQUIPMENT

Communication was maintained between the aeroplane and the place at which measurements were being taken by means of Marconi V.H.F. radio equipment Type H.18, working on a frequency of 121·9 megacycles. Three radio stations were operated, one ("Noisome") inside the aircraft, one ("Loathsome") by the observers, and a third ("Fulsome") in the headquarters of the field party so that the progress of each test could be followed from there.

3.4. THE EXPERIMENTAL WALL

The plan geometry of the wall was designed to fit the Viking. A wing tip clearance of 10 ft. appeared reasonable and was provided by making the span of the wall 110 ft. The side walls were to be 30 ft. deep and the maximum height 40 ft. To permit the experimental wall to be built in stages, tubular steel scaffolding to these dimensions was erected and covered progressively with sheeting of corrugated cement asbestos, the sheets overlapping 4 in. horizontally and 6 in. vertically.

The selection of suitable material to cover the scaffolding was influenced by the expected development

of the investigation. The covering would absorb and reflect some of the applied sound energy and transmit the remainder, the ratio of the incident energy to that transmitted being by definition the sound reduction factor in decibels. Sound reduction factors of different materials are connected by a mass relationship, being approximately dependent on the weight per unit area of a material and on the frequency of the applied sound. Consequently, the heavier the material used, the greater the effect the wall would have immediately beyond it, although at a distance from the wall the reduction would be diminished by the sound coming over and round the wall. As at some distance the reduction would be largely independent of the material used, there seemed little point in having a very heavy construction and, from published data[3], it was found that corrugated asbestos cement sheeting, $\frac{1}{4}$ in. thick with a weight of about $2\frac{3}{4}$ lb./ft.^{2}, would have adequate sound reduction factors. To prevent any leakage of sound between the bottom row of sheets and the ground, the gap there was sealed with a concrete fillet.

3.5. METEOROLOGICAL INFORMATION

The test site was within one mile of the Meteorological Office at London Airport and it was convenient to use the meteorological observations made there. The temperature, humidity and wind strength and direction were obtained each time a test was made and used in the analysis of the results of that test.

4. The Aeroplane as a Source of Sound

There were still two more tests to be made before the screening effect of the experimental wall could be explored. An aeroplane engine had been chosen as the source of sound and had to be operated in such a way as to give the loudest sound possible for a time sufficiently long for a set of measurements to be made. It was found that, at first, nearly one minute was needed to take enough measurements at an observation point to define the sound spectrum there, although this time was later nearly halved as the observers gained more dexterity in using the equipment.

The loudest sound would be offered by an engine when developing maximum power, but two limitations were set on the power that could be drawn from an engine; the first by the possibility of over-heating the engine in the time required for a set of measurements, and the second by the need to prevent the whole

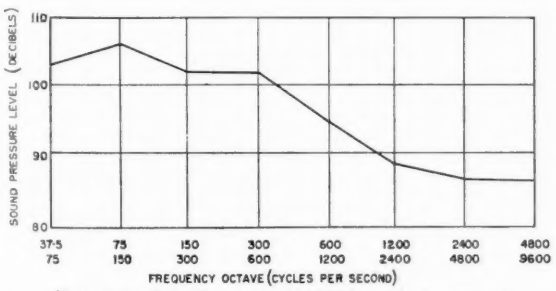

FIGURE 1. Sound spectrum of Viking, 100 feet ahead.

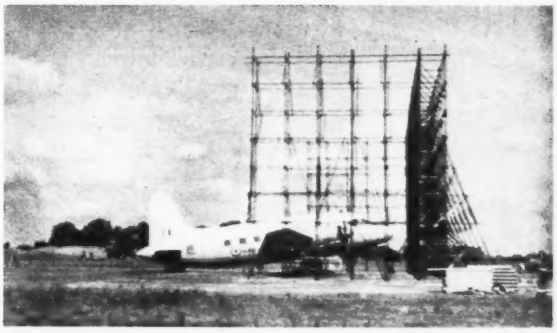

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FIGURE 2. Viking behind unclad scaffolding.

aeroplane over-riding its brakes and chocks. There was no question of using both engines under power at once because of this second limitation; this was no handicap since the sound emission of two engines would only have been 3 decibels greater in each octave than that of one.

Measuring the sound emission of one engine at various engine powers indicated that operating conditions of an engine speed of 1,900 r.p.m., with a manifold pressure of 29 in. of mercury, gave a satisfactory level of sound without causing these limitations to be exceeded. These conditions were then defined as the standard operating conditions for the investigation and the starboard engine was thereafter operated consistently at them.

The next step was to make an accurate determination of the sound emitted by the starboard engine. To do this, the sound pressure levels in each of the eight octaves were measured at five points in line ahead of the aeroplane 100 ft. apart, starting 100 ft. directly in front of the engine which was operated at the standard conditions. The experimental results after correction for the atmospheric conditions obtaining at the time, were then used to obtain faired values of the sound pressure levels 100 ft. ahead of the aeroplane. In this way, more accurate values were established than would have been given by just taking spot readings at a single distance of 100 ft. From the spectrum so obtained, shown in Fig. 1, was then calculated the sound pressure levels in each octave at a number of distances up to 2,500 ft. away from the aeroplane, using a relationship, previously derived, connecting the fall-off of sound and distance in still air. These sound pressure levels were next combined into loudness levels, thus giving a datum against which could be compared the loudness levels to be obtained when the aeroplane was to be placed behind the experimental wall.

The tests with the experimental wall could now begin and Fig. 2 shows the aeroplane within the scaffolding of the wall just before the first area of sheeting was attached.

5. Tests with the Experimental Wall

5.1. RESULTS WITH THE WALL 30 FT. WIDE

The first area of the wall to be clad was 30 ft. wide and 15 ft. high, situated symmetrically ahead of the

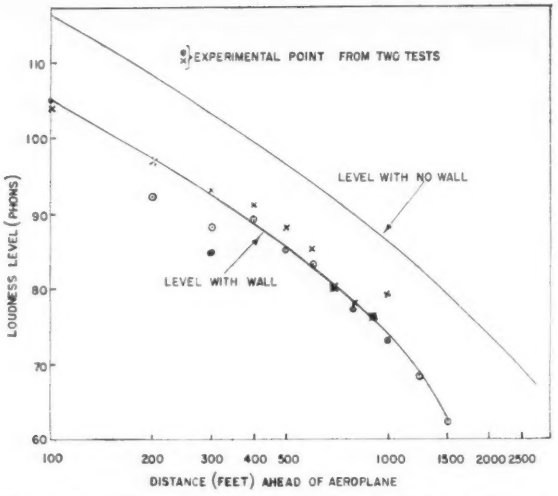
EXPERIMENTAL POINT FROM TWO TESTS
LEVEL WITH NO WALL
LEVEL WITH WALL
LOUDNESS LEVEL (PHONS)
DISTANCE (FEET) AHEAD OF AEROPLANE

FIGURE 3. Screening effect of wall 30 ft. x 15 ft. Aeroplane 20 ft. behind wall.

starboard engine. The nose of the aeroplane was 10 ft. behind the wall, this being as close as was thought safe, so that the starboard engine was about 20 ft. behind the clad area. With the starboard engine operating at the standard conditions, the sound pressure levels were measured directly ahead of the clad area and corrected to a standard atmospheric condition of zero vector wind and a relative humidity of 50 per cent. The loudness levels were calculated and are shown in Fig. 3. Two sets of measurements were made with this arrangement and the experimental points have been plotted separately. It will be seen that over the distance that measurements were taken, the screening effect was about 10 phons, with no decrease of reduction with distance; in fact, the points suggest an increase of screening effect with distance, although this must be a reflection of experimental errors. These results were better than had been hoped for and showed that further work was justified.

It should be mentioned at this juncture that the reduction of the sound pressure levels meant that the range over which measurements could be taken was reduced, since the effect of the wall could be perceived only when the loudness levels caused by the aeroplane exceeded the loudness levels of the local background noise. As the local background was usually between 55 and 65 phons, once the loudness level caused by the aeroplane fell to this further measurements could not be taken. Consequently, the more effective the wall, the shorter the possible range of objective measurement.

The height of the wall was then increased by additions of 5 ft. until a height of 40 ft. was reached. With each increment the sound pressure levels were measured and the loudness levels calculated. The results of these tests are shown in Fig. 4. As the height of the wall was raised, so there was a general increase in the screening effect obtained, although experimental scatter made it difficult to distinguish the precise relationship of screening effect to wall height. There was still no sign of the screening effect falling off with the distance away from the wall.

At each step in the growth of the wall, a second set of measurements was made with the aeroplane pulled back 100 ft. from its standard position. The purpose of these tests was to represent the case of a large aeroplane placed with its tail towards the wall. The results (Fig. 5) indicated that the screening effects were less than those when the aeroplane was in its standard position.

5.2. RESULTS WITH THE WALL 50 FT. WIDE

The width of the wall was then increased to 50 ft. and measurements again taken with the aeroplane in its standard position. Fig. 4 includes these results. Once more there was a rather greater reduction than hitherto.

5.3. THE DEFECTS OF THE WALL

These reductions of loudness level were most encouraging, but an examination of the reductions of sound pressure levels showed that, while the reductions at the lower frequencies were consistent with the sound reduction factors, those at the higher frequencies were well below the corresponding factors. This feature is shown in Fig. 6. Somehow an unexpected amount of high frequency was reaching the far side of the wall.

Some leakage was traced to the joints between adjacent sheets of asbestos cement and this was blocked by sealing the joints with hessian scrim laid on a bituminous compound and painted over with the same compound. Fig. 7 shows the joints partly sealed, but this sealing only stopped the local leakage and was found to make no difference to the sound pressure levels away from the wall.

A further cause was thought to be the exposed scaffolding. It will be seen from Fig. 8 that, at this stage, only about one-third of the total area was clad and

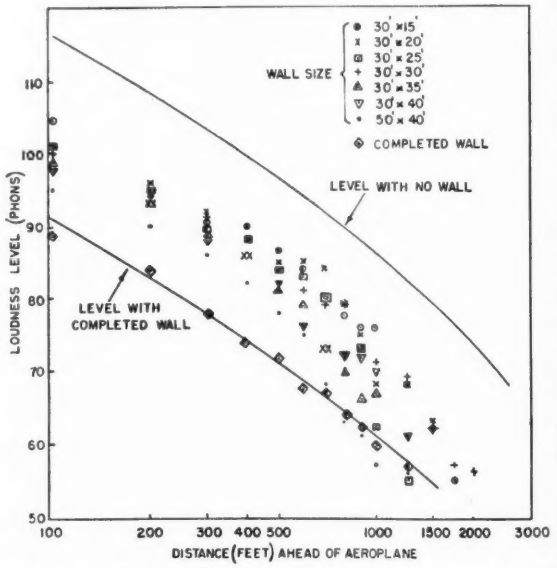

FIGURE 4. Screening effect of wall. Aeroplane 20 ft. back.

a considerable amount of framework remained exposed. The suggestion was that sound was being diffracted round the cylindrical members of the scaffolding and joining the sound transmitted through the sheeting. If this were so, no practicable cure was possible and further progressive covering of the framework would be nugatory. If an extension of the clad area were going to screen more sound, it would also reduce the amount of exposed framework and so reduce the interference. The total reduction would be the sum of these two effects and their apportionment could not be assessed.

This was a disappointment, since it meant that the reductions of sound pressure levels that had been obtained might not necessarily be representative of those given by a wall constructed in some other fashion. Fortunately, the results were, if anything, pessimistic and reductions at least no smaller could be expected from a wall in which these shortcomings were absent. Furthermore, the real effect of the wall was in its reduction of loudness levels and the higher frequencies were now becoming of lesser importance in their contributions to the loudness levels. It was therefore decided to go straight to the fully clad wall and then bring the investigation to a close. After this had been done, as will be seen later, there was evidence to suggest that the exposed scaffolding might not really have been the transmitting agent.

5.4. RESULTS DIRECTLY AHEAD WITH THE WALL COMPLETED

The complete framework was clad, the intention being that all joints should be given the sealing treatment, but a temporary shortage of materials threatened to hold up the test work and it was decided to accept the structure with only about half the joints sealed. The efficacy of a wall had been established in principle, and it was unlikely that much additional information could be obtained from further tests. With the aeroplane in its standard position, as shown in Fig. 9, the usual measurements were made. The

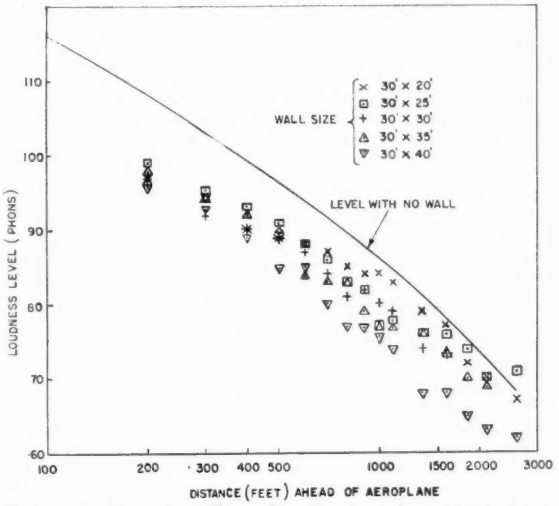

FIGURE 5. Screening effect of wall. Aeroplane 120 ft. back.

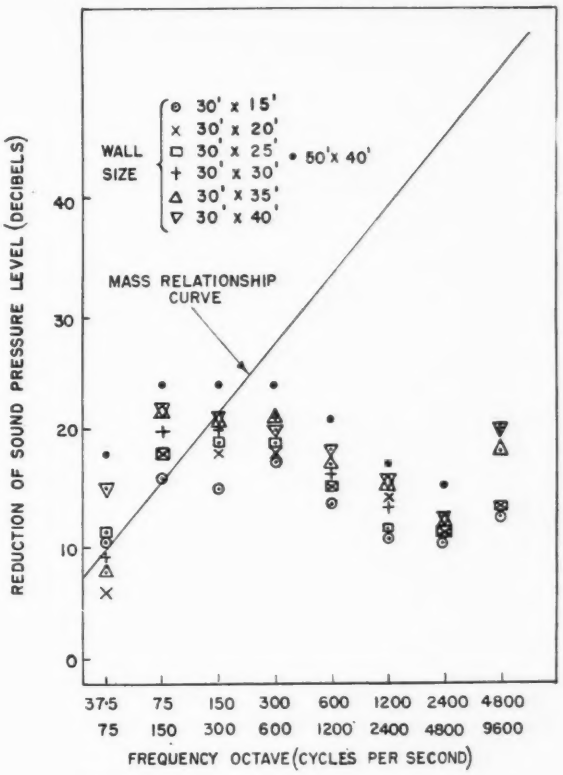

FIGURE 6. Achieved sound reductions at 100 feet.

resultant loudness levels, which have been included in Fig. 4, bore out the previous results by giving a reduction of about 25 phons to the limiting distance of about one-quarter of a mile. Over this range there was no evidence of any decrease of reduction of loudness level with distance.

Although the reductions of sound pressure level obtained in this test appeared to be falling away very gradually as the distance from the wall became greater, there was no indication that the effect of the wall would disappear within the range of audibility of the unscreened sound. Thus the effectiveness of the wall was found to be much greater than was thought possible at the start of the investigation, and the expectations of diffracted sound and scattered sound diminishing the effectiveness were not borne out.

A strange feature of this test was that the reductions of sound pressure levels 100 ft. ahead still showed the same departures from the sound reduction factors as had been obtained previously. Although the exposed scaffolding was blamed in the previous test, this last test showed that the discrepancies still occurred even when there was no scaffolding exposed. These acoustic phenomena have not yet been explained.

With the complete wall, measurements were also taken with the aeroplane placed at three positions, each 30 ft. apart directly in line behind the standard position. The results are shown in Fig. 10, which includes the loudness levels obtained with no wall interposed and

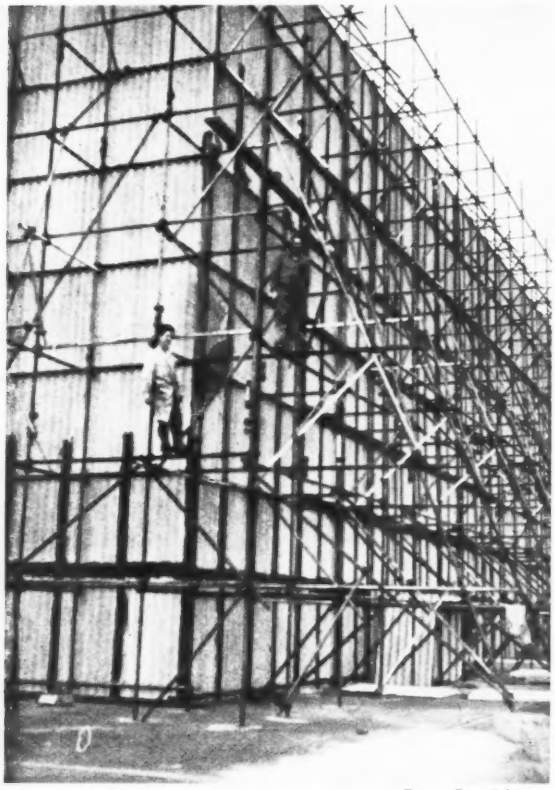

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FIGURE 7. Experimental wall showing joints partly sealed.

those with the aeroplane in the standard position behind the wall. It is evident that the effectiveness of the wall decreases as the distance of the aeroplane from the wall is increased, the screening effect when the aeroplane is in the rearward position apparently disappearing by about 3,000 ft. These results may be compared with those in Fig. 5.

5.5. RESULTS AROUND THE COMPLETED WALL

To find whether the reductions of loudness levels obtained directly ahead of the wall extended round the wall, measurements were made at seven points on the starboard side of the aeroplane. The reductions of loudness levels at each of these points are shown in Fig. 11, corrections being made for the additional attenuation caused by the grassed surfaces lying between the aeroplane and the observation points. The reductions obtained directly ahead were reproduced almost as far as the beam position and fell away only as the line of the front of the wall was passed, decreasing, in particular, in the shadow of the side wall. Thus, the effectiveness of the wall was found to be maintained throughout almost the whole of its geometrical shadow.

Because of the lower limit of measurement imposed by the equipment being used and because of the background noise prevailing while the tests were being made, the full effect of the wall could be directly measured during the day up to a distance of only 1,500 ft. or so. To assess the effect of the wall at greater distances, a test was made in the middle of a windless night when the background noise was least. Aural observations were made at various points ahead and on the beam of the wall. At points between half and one mile from the wall it was just possible to hear the sound of the engine when it was operated at the standard conditions, and at a position one quarter of a mile obliquely in front of the wall, the sound was taken to be that of an idling engine of a light aircraft. In comparison, the sound of an engine running in the maintenance areas one and a half miles away was most noticeable. These observations suggest that the effectiveness of the wall was maintained much farther than the distances over which direct measurements could be taken and, directly ahead of the wall, probably extended to at least one mile.

Some concern had been expressed lest the wall, in screening positions ahead of it, might, by reflection, increase the loudness levels behind it. At face value, this concern was ill-founded. Behind the wall, the loudness level would have two components, one coming direct from the aeroplane and the other reflected from the wall. But, assuming the two to be equal, the resultant would be only about 3 phons greater than either, a difference which would not be noticed. For interest, measurements were made of the sound pressures 200 ft. directly behind the aeroplane, once when it was right out in the open and once when it was in its standard position behind the wall. No significant differences could be detected between the two results, demonstrating that the reflected sound would cause no noticeable increase.

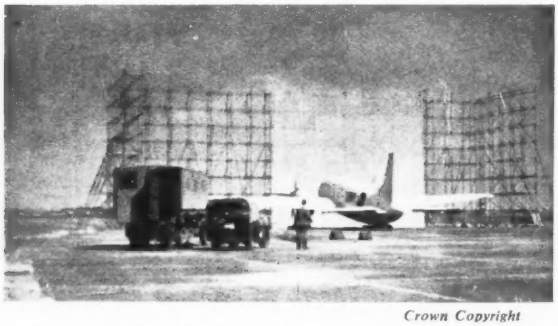

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FIGURE 8. Experimental wall 50 ft. x 40 ft. from rear.

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FIGURE 9. Viking in standard position. Wall completed.

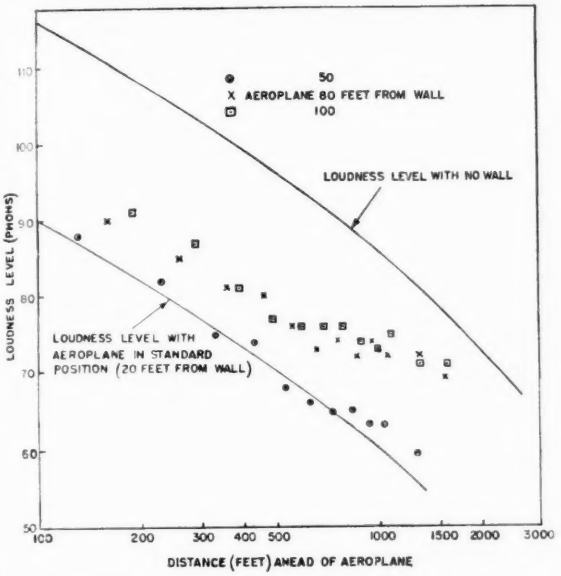

FIGURE 10. Effect of moving aeroplane away from completed wall.

5.6. TESTS WITH THE COMET

To conclude the formal investigation, and through the co-operation of British Overseas Airways Corporation, the second prototype Comet 1, G-ALZK was placed behind the wall while an engine test was being made (Fig. 12). In order not to interfere with the operational programme of the Comet, sound pressure level measurements were made at only one distance—100 ft. in front of the wall. By taking measurements later when the Comet had returned to its base, it was possible to obtain a direct comparison of the sound pressure levels with and without a wall interposed. The spectra obtained are shown in Fig. 13. The reductions of sound pressure level per octave which were obtained were similar to those given by the tests made on the Viking, although there were differences in the first two octaves rather greater than would be caused by experimental error. A reason for this may be that the efflux sound, which is mainly of low frequency, is carried back within the efflux and spreads fanwise behind the wall. However, the reduction of loudness level was no less than that obtained when the Viking was placed behind the wall.

5.7. THE VARIATION OF SCREENING EFFECT WITH SIZE OF WALL

The experimental wall had proved more effective than had been expected originally but had displayed characteristics which frustrated the intention to determine the variation of screening effect with wall size. The test programme had been designed so that the screening effect would be determined for each of 25 sizes of wall, from which it should have been possible to deduce the relationship between screening effect and wall size. It was expected that, for a given width, there would have been found a height beyond which there would be no further increase of screening effect, since the sound getting round the sides of the wall would then be more than that getting over the top and reductions of the latter would not sensibly diminish the total and similarly, for a given height, there would be an optimum width. In fact, only eight sets of measurements were taken with the aeroplane close to the wall and six sets with it pulled back. The average reductions of loudness level over the first 1,000 ft. were examined but, while it was found that the screening effect increased with the solid angle the wall subtended at the aeroplane, there were insufficient points, both to define reliably the variation and to show discontinuities when an optimum height or width was reached.

6. Miscellaneous Tests

It was suggested that natural features, such as trees and buildings, might be used to give much the same screening effects as a running-up pen and tests were made to explore these possibilities.

6.1. THE SCREENING EFFECT OF TREES

The screening effect of trees was investigated at Blackbushe Airport, where there are wooded tracts fairly close to surfaced areas on which aircraft could be parked. Through the co-operation of British European Airways, a Viking was placed close to the boundary of the airport and one of its engines was operated at the standard conditions used during the principal investigation. Two sets of measurements of sound pressure levels were made, one across a spur of woodland and one into continuous woodland. In each case, the woodland contained closely planted trees of an average height of 15 ft. and with thick foliage down to the ground. Because of bad weather at the time, it was not possible to make the tests over a sufficiently wide range of distances and the results do not lend themselves to detailed analysis.

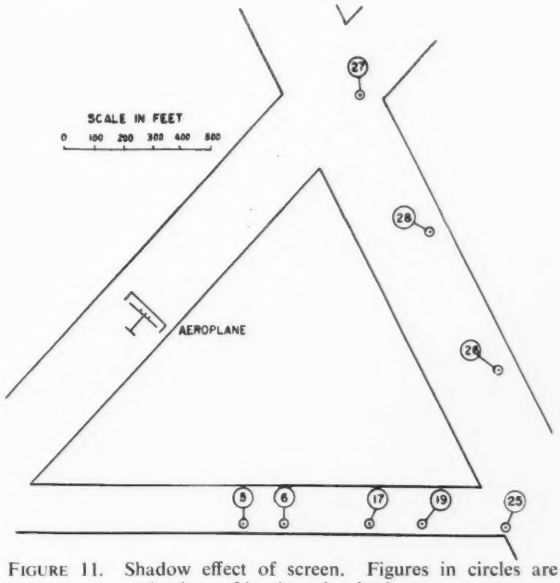

FIGURE 11. Shadow effect of screen. Figures in circles are reductions of loudness level (phons).

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FIGURE 12. Comet I, G-ALZK, behind completed wall.

From Fig. 14 it will be seen that in traversing the spur of woodland there might have been a reduction of about 5 phons caused by the 100 ft. wide belt of trees, but this is by no means certain. No reduction at all comparable with that obtained with the experimental wall was obtained. Within the continuous woodland the loudness levels are less than those that would have been expected in the absence of trees, but the rate of fall-off of loudness level with distance is substantially that over open country, which casts doubts on the validity of the results.

These tests, although not conclusive, indicate strongly that trees are unlikely to constitute an efficient acoustic barrier and that a belt of trees, two or three trees thick, would be useless in preventing the dissemination of sound.

6.2. THE SCREENING EFFECT OF BUILDINGS

To assess the screening effect of buildings, arrangements were made for three Argonauts in turn to run one engine at a time, the first aeroplane being placed with the operating engine opposite the closed doors of a hangar, the second with the operating engine opposite a narrow gap between two adjacent hangars, and the third placed so that there would be no screening by any nearby buildings. Measurements of the sound levels were taken some 3,000 ft. away. Although the noise of other aircraft interfered with the test, it could be deduced that the maximum possible screening effect of the hangar doors was 6 phons at this distance. There was no purpose therefore in repeating the test under more favourable conditions, since there would have been even less reduction in the second position, and a maximum reduction of 6 phons was not considered sufficient to warrant further tests.

7. The Results Reviewed

The investigation only partly reached its objective, although much of what was attained was useful and encouraging. That the experimental wall, even with its shortcomings, could give a reduction of 25 phons throughout most of its geometrical shadow and for probably a mile and possibly more, was far beyond the starting expectations. The reduction of loudness level obtained can be assessed by assuming a noise of some loudness, imagining a noise half as loud, then a noise half as loud as this, and finally a noise about half as loud as the last. This may be rather stretching the limits of imagination but to appreciate a reduction in one step to one-eighth the original loudness is beyond imagination. Expressed in another way, the reduction represents the difference in noise at the kerbsides of a main road and of a suburban street.

Because of the acoustic characteristics of the experimental wall, the attempt to obtain design data failed. The scanty information that was obtained about the variation of screening effect with size cannot be used to calculate the size of wall needed to give a specified reduction of noise from a particular type of aeroplane. This failure is to be regretted because there may be occasions when only partial noise abatement might be acceptable and it would be uneconomic to obtain a greater reduction than was necessary by building a larger wall. At the same time, the application of the results obtained with the experimental wall tailored to fit the relatively small Viking, to the abatement available for a larger type of aeroplane, cannot be directly deduced. Only the principle has been established; not the details.

The question of economy is of importance. The benefits that can be obtained from running-up pens have to be balanced against the costs of providing the pens. Apart from any social or political considerations, there is clearly a lower limit to the degree of noise abatement that justifies special effort. Thus, the abatement available by making use of existing features, such as trees or buildings, can be apparently at the most 6 phons. A reduction of this order is only just noticeable and is insufficient to justify special effort. At the other end of the scale, a reduction of 25 phons is a major improvement. It is probable that, for a given aeroplane, the effect of a running-up pen increases with the size of pen and then becomes constant. Also, there may be a size after which the rate of improvement with size becomes small, and a heavy increase of cost may produce little further benefit. This was the sort of information that was sought, but which was not obtained.

The investigation was designed as an acoustic one, and operational aspects were not explored. By its nature a pen offers protection to a limited area; behind it there is no abatement (although there is no intensification). Since a pen is a permanent erection, it has to be so orientated as to face the area to be protected, and it is

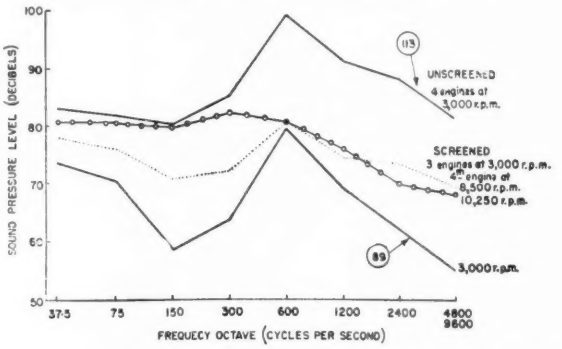

FIGURE 13. Comet I sound spectra. 140 feet ahead of engines. Figures in circles are loudness levels (phons).

most efficiently used when an aeroplane is put in it nose first with the engines as close to the walls as possible.

Conditions may require the aeroplane to face into the wind so that on some occasions it might have to be in the pen tail first and there would be some loss of acoustical efficiency. An attempt was made to determine this loss, but the application of the results to larger pens and larger aeroplanes is not reliable. Furthermore, running the engines with the aeroplane tail-first in a pen may cause tail-buffeting and, with turbine engines, there may be unusual turbulent effects as far forward as the engine intakes. The structural and heating problem associated with slipstream or jet effluxes are probably not difficult to solve, although the experimental wall was not subjected to the slipstream of the Viking since it had not been designed to withstand the resultant loads.

Another operational aspect is the ease, or otherwise, of manoeuvring aeroplanes into and out of pens, either tail-first or nose-first. If the pens are to be tailored to fit an aeroplane as closely as possible, making proper allowance for the different geometry of different types of aeroplane, the greater the difficulty there will be in getting aeroplanes into and out of the pens. These, and allied operational problems, have yet to be investigated. They may present no difficulties, or they may be so fraught with difficulties as to preclude the use of running-up pens.

As a result of the present investigation, and with the intention of exploring the operational aspects, the Ministry of Civil Aviation has now ordered the construction of a prototype running-up pen at London Airport. Experience on the use of this pen will show the practical extent to which a running-up pen can be employed in abating the noise of engine running.

ACKNOWLEDGMENTS

The investigation was made possible by the co-operation of, and assistance from, many branches of the Ministries of Civil Aviation and of Supply, from the Department of Scientific and Industrial Research, from British European Airways, and from British Overseas Airways, to whom acknowledgment is most gratefully made. In particular, the author would like to express his appreciation of the support he received from the members of his field party: D. F. Hedges, J. G. Roberts and Miss P. E. Copland.

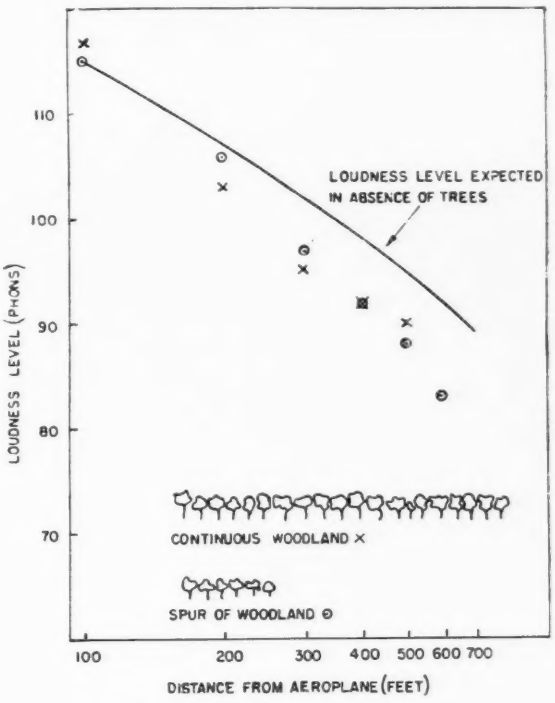

FIGURE 14.- Effect on sound propagation of:—
(*i*) A spur of woodland
(*ii*) Continuous woodland.

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Design Criterion for Fatigue of Wings

by

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1. Introduction

Exactly what constitutes a design criterion is a matter on which there may well be differences of opinion. For practical purposes design criteria may be taken to be empirical numerical rules to aid the designer in forming his initial conception of a design. The formulation of such rules for aircraft fatigue is still a matter of some difficulty. Not only is the subject of aircraft structural fatigue still in its infancy, but its study has to be linked with systematic experiment in a somewhat unusual way.

In the criteria described in this paper, the structure has first to be subjected to a standardised laboratory test. This test is itself a gross simplification since it has to represent in a rough way a diversity of conditions occurring in flight. Experience so far indicates, however, that the single standard test, so essential for simplicity, is satisfactory provided that it is carefully chosen. The specification of the condition of test thus becomes an essential part of the criterion.

With the test defined, the complete criterion has next to stipulate the results that are to be considered acceptable. The test itself consists of a specified alternating load superimposed on the loads occurring in steady level flight. The second part of the criterion prescribes a minimum number for the loading cycles required to produce fatigue failure.

In the criteria here presented the aim has been to achieve consistency for a diversity of operating conditions, and a variety of aircraft types. A number of criteria are successfully derived as a continuous series, with each one more general and, so far as can be judged, more reliable than the one preceding it. Thus the first criteria is extremely simple, while the last involves a number of parameters. The process described follows closely the actual course of development in recent years, as the field of study has widened and as knowledge has been gained.

The second consideration has been to achieve an acceptable degree of overall severity. On the assumption that the formulae are consistent to the degree claimed, they could still be as a whole too severe or not severe enough. On this aspect it is not possible to be dogmatic in the present state of knowledge; and even if the form of the criteria is satisfactory, an arbitrary adjustment may be required by means of empirical factors. To avoid confusion on this issue, however, each criterion in the series is consistent with the one immediately preceding it for the conditions that were originally foreseen, although more general in its application.

The results of this progressive modification are interesting. The final and most complex criterion, derived step-by-step from the earliest and simplest, prescribes standards that are not dissimilar to those obtained from the latest statistical study of gusts, using records obtained by means of the counting accelerometer.

Notation

The following simple notation is used consistently in all the criteria:—

- $\pm A$ the alternating load applied in a fatigue test, and superimposed on the steady load corresponding to undisturbed level flight. More generally A may define a complex loading system
- A_0 an over-riding minimum value for A, when A is defined by a general formula
- N the required number of loading cycles which the structure has to withstand before fatigue failure occurs. Normally N is an appropriately selected "mean" value of a series of tests made under identical conditions (*see* Section 2)
- L (hours) the required operating life in flying hours
- M (miles) the required operating life expressed as total distance travelled (miles)
- V (m.p.h.) the operating speed in true miles per hour

2. Test Procedure

The fatigue criteria for wing structures that are considered here all embody data obtained from laboratory tests. Before actual criteria are postulated, therefore, it is desirable to have an outline of the test procedure.

The fatigue tests fall naturally into two classes, (*a*) tests on components such as joints, and (*b*) tests on complete wings. For most purposes component tests are the main source of data. Complete wing tests are expensive in time, effort and money; and ordinarily are used only as overall checks on designs for which the more critical components have already been investigated individually.

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In principle the criteria are related to a form of test corresponding to a single set of loading conditions; or, in other words, they are based on a standardised test. This procedure is desirable for simplicity and experience shows that it can be made a reasonably safe basis for design assessment. It is necessary, however, that the standard test be carefully chosen and its definition is an essential part of any of the criteria.

In making a test, the structure is first loaded to reproduce as accurately as possible the loads occurring in steady level flight. In simple tests, *e.g.* tests on a main joint, an alternating load $\pm A$ is then superimposed, its value being that specified in the particular criterion being used. In more complex loading cases the alternating load becomes a single numerical factor defining a complex loading system in which loads bear fixed and specified ratios to each other.

The alternating load is applied in steady cycles that are repeated until failure occurs. The number of cycles is then noted and recorded for use in applying the criterion.

Because of variation of nominally identical specimens, the results of a single test are unreliable. At least six tests are required normally and three is the absolute minimum. The mean value N of the cycles to destruction is then determined for use in the formulae that constitute the criterion. Thus, on this basis, each criterion specifies a minimum value for the mean number of cycles N for the specified alternating load $\pm A$.

A word is necessary about the determination of this mean value. Difficulties may arise because of the shape of the endurance curve. Conventionally such a curve is obtained by plotting alternating load against the logarithm of the endurance, or cycles to destruction. As is well known, the average endurance curve flattens appreciably at the lower values of alternating load, and small changes in alternating load produce disproportionate changes in endurance. From the standpoint of variability it would be preferable to make all repeat tests correspond to a single value for endurance, so that alternating load would be the dependent variable. Unfortunately this is impossible because the endurance cannot be predicted. Endurance must, therefore, always be the dependent variable.

In the past, the mean value of the endurance has usually been the simple arithmetical mean of the results of individual tests. This is probably satisfactory when the variation is not great, but there are already indications that the logarithmic mean is more appropriate, and it is certainly safer*. It should be understood, however, that this does not represent the last word on the determination of the effective mean endurance; and the criteria are presented with reservations as to how it may have to be interpreted in unusual cases.

While a single form of test—with repetitions only as required to establish variability—is the basis of the criteria, it is often useful to explore further the behaviour of the specimen, especially at alternating loads slightly above and below the standard load that is specified. In this way a portion of the endurance curve may be established. This information has general value and may lead to greater accuracy in the assessment of endurance for use in the design criterion. It may become essential, moreover, if the simple criterion is replaced at a later stage by a more exact analysis.

*This suggestion is due to W. A. P. Fisher.

3. The Simple "Ultimate" Criterion

In the early days of fatigue investigation of aircraft wing structures, little was known as to the standard that it was reasonable to expect. Before anything resembling a design criterion could be postulated it was necessary to test a large number of aircraft structural components. Various criterion were produced and rejected as experience was gained and ultimately, one which had some degree of permanence and justification was obtained. This took the form

$$\left.\begin{array}{l} A = \pm 7\tfrac{1}{2} \text{ per cent. of the static ultimate load} \\ N = 2 \times 10^6. \end{array}\right\} \quad (1)$$

where A is the alternating load superimposed on the load occurring in undisturbed level flight and N is the mean number of cycles to destruction.

As a design criterion for safety this criterion is no longer in general use in the precise form in which it is given, but it is important for two quite different reasons. In the first place, it forms the basis of all the subsequent and more elaborate design criteria described in this paper. Although imperfect in several respects it is based on much experiment and, for the conditions prevailing at the time when it was evolved, it set a worth-while and not unattainable target for the designer.

In the second place, the criterion still remains a criterion of design efficiency in relation to fatigue, and a test of design skill irrespective of particular operational conditions that have to be encountered. It enables one design to be compared with another in common terms, whether they are for different aircraft or for alternative versions of a given component of the same aircraft.

To be effective as a criterion of design efficiency, however, this criterion must be associated with the ultimate static strength actually attained, and not merely that specified as a design aim. In the use of the static ultimate lies the main limitation of the criterion, and perhaps its only limitation. Fatigue strength is expressed as a fraction of the static strength, and the force of the criterion, therefore, could be circumvented by manipulation of the static strength instead of improvement of the fatigue strength. No designer would deliberately misuse a design rule in this way, but the possibility of error or misunderstanding must not be overlooked. Misconceptions are most likely to arise when structures in different materials are being compared, and especially when these have different fatigue-to-static strength ratios. There is nothing that can be done about this, except to use discretion in making comparisons.

4. The Gust Ultimate

The main concern of this paper, however, is criteria for design to attain the required measure of fatigue resistance, and so avoid fatigue failures in flight. From

this standpoint design efficiency is a secondary consideration. As a design criterion for safety the previous criterion may fail completely, for two main reasons that are both associated with fatigue loading being expressed in terms of static ultimate.

In the first place, an aircraft may be designed to ultimate factors corresponding to severe manoeuvres which bear little or no relation to the conditions giving rise to fatigue failure. This almost always arises with fighter aircraft, is quite likely to arise with training aircraft, and is not necessarily excluded for transport aircraft, particularly if they are designed for alternative operational roles.

In the second place, the designer may deliberately and justifiably choose to work to higher ultimate factors in order to increase the fatigue life. Thus, for example, by increasing the cross-sectional area of members of a structure, both fatigue life and ultimate static strength are increased at the same time.

The consequences are the same in both cases. The previous criterion gives no recognition of increased fatigue strength when such is obtained by means which produce correspondingly increased ultimate strength. To overcome this objection, the actual static ultimate in the criterion is replaced by the *required* ultimate factor in the 50 ft./sec. static gust case. In this way the fatigue hazard becomes definitely linked with gust effects. Furthermore, by the stipulation "required" in the criterion the designer ceases to be penalised for high static ultimate strength, whether provided voluntarily or to meet a severe manoeuvring case.

On this basis the criterion takes the form

$$\left.\begin{array}{l} A = \pm 7\tfrac{1}{2} \text{ per cent. of the required factored load for 50 ft./sec. gust case} \\ N = 2 \times 10^6. \end{array}\right\} \quad (2)$$

For the wings of most aircraft it is probably safe to regard gusts as the main fatigue hazard and to base the criterion upon them, provided that some margin is allowed to cover other effects, particularly landing and taxi-ing. When the 50 ft./sec. gust case is not severe the margin for general use may not be adequate. For safety, therefore, it is desirable to specify an over-riding minimum A_0 defined by:—

$$A_0 = \pm 0{\cdot}25 \text{ times the load occurring in undisturbed level flight} \quad . \quad (2a)$$

It should be noted that this over-riding clause is only likely to be operative in rare and somewhat extreme cases.

5. Simple Life Criterion

For design purposes there are advantages in having a direct criterion such as the last, but behind such a criterion there must be an assumption as to life expected. In the criterion given that life is 30,000 hours.

There may well be objections to the making of such an assumption. Operators of aircraft and others may be prepared to accept the views of fatigue specialists on the subject of fatigue, but have their own views on what life is wanted. Clearly, therefore, the responsibilities for specifying a required life and for determining the design standards to achieve that life should be separated.

Furthermore, irrespective of whoever decides the required life, it is a fact that some aircraft fail to meet the criterion as given. Yet, provided that the flying life is properly restricted, such an aircraft may be completely free from fatigue hazards within the period specified.

In transforming the previous criterion it is reasonable to assume that the endurance (expressed as cycles to destruction in the standard test) is proportional to the flying hours. If the previous criterion be taken as covering 30,000 flying hours the new criterion becomes:—

$$\left.\begin{array}{l} A = \pm 7\tfrac{1}{2} \text{ per cent. of the required factored load in the 50 ft./sec. static gust case} \\ A_0 = \pm 0{\cdot}25 \text{ times the load occurring in undisturbed level flight} \\ N = 67L \end{array}\right\} \quad (3)$$

where L is the life in flying hours.

To retain the same general form as for the earlier criteria, this third criterion specifies the test endurance required for a given life. It may, however, be used in the reverse way. If the endurance N in the standard test is insufficient to meet the criterion, the appropriate reduced life can be calculated.

6. The Effect of Operating Speed

The criteria so far considered were evolved mainly for a restricted range of types with roughly the same operating speeds. For some of the high-speed and newer types of aircraft these criteria may be unreliable if, as is now generally accepted, gusts are the main cause of fatigue failure.

The last criterion takes into account in some measure the effect of speed on gust loadings but it does not take into account the frequency with which gusts are encountered. Gusts are disposed geographically, and the faster an aircraft travels the more gusts it will encounter in a given time. The inconsistency does not arise if life is measured in distance (miles) and not in time (hours).

The criterion may, therefore, be transformed to a more generally applicable form, provided that the operating speed with which it has hitherto been mainly associated is known. The best estimate for this is 200 m.p.h., and on this basis the new criterion becomes:—

$$\left.\begin{array}{l} A = \pm 7\tfrac{1}{2} \text{ per cent. of the required load in the 50 ft./sec. static gust case} \\ A_0 = \pm 0{\cdot}25 \text{ times the load occurring in undisturbed level flight} \\ N = LV/3. \end{array}\right\} \quad (4)$$

where L is the life in flying hours as before and V is the operating speed in miles per hour.

The third equation in the criterion could equally well be written

$$N = M/3 \quad . \quad . \quad . \quad (4a)$$

where M is the life in miles travelled. It is customary, however, to record life in flying hours and the original form of the criterion, as given in (4), is the more likely to be used. The operating speed is a true speed

corresponding to geographical distance, and will usually be an average speed. It is also known as the " block-to-block " speed on scheduled air routes.

7. The Direct-Gust Criterion

In the conception of a fatigue criterion for design based upon the 50 ft./sec. static gust case there is a merging of two distinct ideas. One is the expression of the fluctuating load as a percentage of the ultimate static strength of the structure. The other is the desire to recognise that gusts are the main cause of fatigue failure.

In these two objectives taken simultaneously there is some measure of inconsistency. For most transport aircraft, the 50 ft./sec. gust case over-rides the other stressing cases for wings. The expression of the alternating load in terms of the static ultimate thus indicates the degree of difficulty likely to be encountered in meeting the criterion, and enables rough comparisons to be made between different designs. As mentioned earlier, this advantage tends to disappear if the designer voluntarily exceeds the required standard of static strength laid down for the gust case, or if he has to over-ride it by a compulsory manoeuvring case.

On the other hand, for reasons yet to be given, the static gust case does not give a realistic representation of the gust loadings which give rise to fatigue failure. Whatever the incidental advantages of the manifest relation with the static ultimate, it is clear that correct representation of fatigue loadings must be the primary aim in producing a design criterion for safety. The next stage, therefore, is to produce a gust case specially for fatigue; and this requires the alternating load to be defined as the superimposed load produced by a gust of specified velocity.

The static gust case fails as a true criterion for a number of reasons. In the first place, the static load includes the steady load as well as that superimposed by the gust. The high gust velocity of 50 ft./sec. is not in itself an objection if it can be assumed, as is reasonable for simple design criteria, that the superimposed load is proportional to gust velocity. The use of $7\frac{1}{2}$ per cent. of the static ultimate implies the acceptance of this rule; but true proportionality is lost through the inclusion of the steady load, which bears no relation to the fluctuating loads that the alternating load is intended to represent.

The static gust case also fails as a true basis for a fatigue criterion for another and quite different reason, which is concerned with forward speed of the aircraft. The static gust case is applied for flight at the " design cruising speed." Most aircraft operate at speeds appreciably below this. In any case, forward speed is a significant parameter* in defining load and must be taken into consideration. The fact that it may be difficult to specify in early design stages does not affect this issue. It must appear in the criterion so that its significance is recognised as a potential cause of serious error.

Finally, there is the complication of factors of safety. In the static gust case the factor of safety is 1·5. This figure does not necessarily have any bearing on safety standards for fatigue. At this stage it is not proposed to specify a factor of safety for the alternating load in the new case, and the gust velocity for the direct gust criterion is to be, in the first instance, an overall " factored " gust.

The previous criterion based on the static gust case and the proposed direct gust case can be related when the overall static factor is known and also, the operating speed ratio. The required number of cycles is to remain unaltered, and only the alternating load has to be re-defined. To make the transformation on an empirical basis it is necessary to decide the conditions under which the previous static ultimate criterion (4) was deemed to be correct. It is assumed that it is correct for an overall static load factor of 5·0 and an operating speed of 80 per cent. of the design cruising speed.

By a simple calculation (*see* Section 8) it may be shown that the new value for " factored " gust velocity is 10 ft./sec., on the assumption that superimposed gust loads are proportional to gust velocity and to forward speed. The new direct gust criterion thus becomes

$$\left.\begin{aligned} A &= \pm \text{ the load superimposed on level flight by a gust of 10 ft./sec. equivalent (or indicated) velocity at the operating equivalent speed of the aircraft} \\ A_0 &= \pm 0{\cdot}25 \text{ times the load occurring in undisturbed level flight} \\ N &= LV/3. \end{aligned}\right\} \quad (5)$$

8. Comparison Between the Direct and Static Gust Criteria

It is worth while making a comprehensive study of the relative severity of the two fatigue criteria, based respectively upon the static gust case and the direct gust case. The static gust criterion has been widely used and it is clearly necessary to have a complete understanding of the repercussions from changing over to the direct gust criterion. Furthermore, even when reference to the static gust criterion is no longer necessary, it is still desirable to know the alternating load for the new criterion in terms of the ultimate load for the static gust case.

It is convenient to work first in general terms on the assumption that, for any specified values of the overall static gust factor and speed ratio respectively, the two criteria give the same alternating load. In other words, it is assumed initially that the precise formula for the alternating load in the new direct gust criterion has not been decided upon. Having obtained the general formula, the transformation which fixes the new criterion can be shown, and this is followed by the comparison of the two criteria.

For the calculation the following notation is used:—

F = the overall static gust factor

f = the alternating load expressed as a percentage of the static ultimate

v = the " factored " gust velocity for the direct gust case

r = the speed ratio, *i.e.* the operating speed divided by the design cruising speed

*This effect is additional to the effect of speed on gust frequency discussed in Section 5.

The starting point in the calculation is the overall static gust factor F which is virtually the required ultimate strength expressed non-dimensionally. By taking out the factor of safety (1·5) and subtracting the component of load corresponding to undisturbed level flight, the superimposed gust load becomes

$$\frac{F-1{\cdot}5}{1{\cdot}5}.$$

From this the superimposed gust load for the direct gust criterion is determined on the assumption that the superimposed gust load, in general, is directly proportional to gust velocity and to forward speed. Hence the new alternating load is

$$\frac{(F-1{\cdot}5)vr}{75}.$$

By equating this to the alternating load as expressed by a percentage f of the ultimate load, the following master equation is obtained:—

$$vr=\frac{0{\cdot}75\,fF}{F-1{\cdot}5}.$$

To carry out the original transformation the substitutions

$$F=5{\cdot}0,\quad r=0{\cdot}8,\quad f=7{\cdot}5$$

are made, giving the gust velocity v for the direct gust criterion

$$v=10{\cdot}045.$$

This figure is then "rounded-off" to give a velocity of 10 ft./sec., which is sufficiently accurate for the present purpose.

From this stage the gust velocity is taken as fixed at 10 ft./sec., and the three quantities F, r and f are allowed to vary. In this way the new direct gust criterion can be related to the previous static gust criterion, and Table I indicates the result.

In commenting generally on these figures it is convenient first to assume a speed ratio of 80 per cent. and to refer to the heavy curve in Fig. 1. It is seen that,

TABLE I

ALTERNATING LOAD FOR THE DIRECT GUST CRITERION (5)* EXPRESSED AS A PERCENTAGE OF THE REQUIRED ULTIMATE FOR THE 50 FT./SEC. STATIC GUST CASE

Overall static gust factor F	*f/r for general use where r = operating speed / design cruising speed*	*f for operating speed 80% of normal top speed r = 0·8*	*Over-riding minimum f = 25/F*
3	6·67	5·33	8·33
3·5	7·62	6·10	7·14
4	8·33	6·67	6·25
5	9·33	7·47	5·00
6	10·00	8·00	4·17
7	10·48	8·38	—
8	10·83	8·67	—

*Applicable also to the criterion (6) (*See* Section 9).

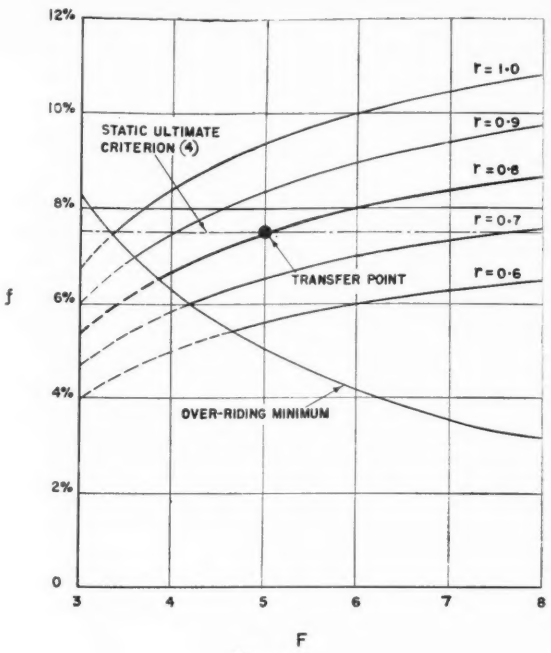

FIGURE 1.

for an overall static gust factor of 5·0 (transfer point), the alternating load in the direct gust criterion is approximately 7½ per cent. of the static ultimate, this being the condition at which the two criteria are made to coincide.

As the overall static gust factor increases above 5·0, the alternating load becomes an increasingly higher percentage of the static ultimate, and the new direct criterion becomes increasingly more severe than the previous static ultimate criterion.

Conversely, as the overall static gust factor is reduced below 5·0 the alternating load becomes a smaller percentage of the static ultimate, and the new criterion becomes progressively less severe than the previous static ultimate criterion. In this region, however, the over-riding minimum for alternating load becomes operative, and sets a limit to the relaxation which the new criterion can give.

An operating speed ratio of 80 per cent. is assumed as a reasonable estimate for the purpose of this comparison. It is not intended to imply, however, that this ratio is to be used automatically in applying the direct gust criterion. The value must be that appropriate to the particular aircraft and to the conditions under which it is to operate. The general curves of Fig. 1 indicate that the changes produced by introducing speed into the criterion may be even more significant than those produced by introducing a direct gust case to define alternating load.

9. Factors of Safety for Fatigue

The empirical criteria given here do not strictly require to be associated with specific factors of safety. Based on experience, they indicate directly the standard

that has to be attained; and the empirical figures that they incorporate may be regarded as taking into account whatever margins of safety are deemed to be necessary.

The last criterion, however, calls for a special gust case, and this introduces a mental picture of some condition that, although somewhat arbitrarily chosen in the first instance, is subsequently treated exactly. The supposition has to be accepted that a single standard test can adequately represent the diversity of conditions. When this principle is translated into terms of the gust criterion, the hypothetical condition is obtained in which an aircraft encounters a series of gusts having the same velocity, but acting alternately " up " and " down."

Now the criterion as given for the direct gust case shows no margin of safety directly. Hence if such margin exists it is provided in the severity of the gust case itself. To obtain the appropriately representative gust case, therefore, it is necessary to introduce an appropriate numerical factor of safety, adjusting the gust velocity to give the same loading standard as before.

In deciding what the " factor of safety " should be, it is necessary to bear in mind that it is not merely a factor of safety in the strict sense. It has to make allowance for the fact that, of the various values of endurance obtained in identical tests, some " mean " value is deliberately used in the appropriate formula instead of the probable minimum on which all-round safety must depend.

Furthermore, the tendency for endurance to change considerably with small changes of alternating load, and hence also with small changes in fatigue strength, has to be taken into account. Thus, in the extreme case—not likely to be fully attained in practice—of a flat endurance curve, a margin on endurance would have no significance.

In consequence it is desirable to provide the main safeguard by means of a factor of safety on the applied alternating load, and to make this high enough to take into account that some kind of average structures are being considered, and not the worst that is likely to occur.

With these considerations in mind, the figure proposed for the " factor of safety " on alternating load is 1·25. This gives the criterion in the new form

$$\left.\begin{aligned} A &= \pm 1{\cdot}25 \text{ times the load superimposed on the level flight loading by a gust of 8 ft./sec. equivalent velocity at the operating equivalent speed of the aircraft} \\ A_0 &= \pm 0{\cdot}25 \text{ times the load for undisturbed level flight} \\ N &= LV/3. \end{aligned}\right\} \quad (6)$$

This criterion (6) gives exactly the same numerical standards as the previous one (5). The advantage of the new form is that it indicates exactly what gust velocity purports to be representative of the conditions encountered in flight. This is one step farther towards linking the criterion with the more exact calculations that may supersede it when statistical figures for gusts are available.

It is of interest that the gust velocity of 8 ft./sec. obtained for the new criterion (6) is in the region of greatest damage, as judged in the light of existing knowledge of gust spectra obtained by actual measurement.

10. An Alternative Direct-Gust Criterion

The last criterion marks the proper termination of the evolutionary process in which each criterion bears some logical relationship to the one which precedes it. There is a possibility, however, of going one step farther.

The objective for the criterion now proposed is primarily to reduce the time expended in testing. To this end the gust velocity, and hence the alternating load, is arbitrarily increased by 25 per cent. and the required endurance reduced appropriately.

The extent of this reduction of required endurance involves some degree of generalisation, which may be open to criticism. The correct reduction depends upon the shape of the endurance curve. In the past a good working rule has been that an increase of 25 per cent. on alternating load reduces the endurance to one half of its original value. This rule is used to give the new alternative criterion:—

$$\left.\begin{aligned} A &= \pm 1{\cdot}25 \text{ times the load superimposed on the level flight loading by a gust of 10 ft./sec. equivalent velocity at the operating equivalent speed} \\ A_0 &= \pm 0{\cdot}3 \text{ times the load for undisturbed level flight} \\ N &= LV/6 \end{aligned}\right\} \quad (7)$$

The new criterion is not necessarily less representative of reality than the preceding one. The best representative figure for gust velocity is not known at present and 10 ft./sec. may have as much justification as 8 ft./sec.

Furthermore, there is some advantage in working to a higher alternating load, provided that the required endurance is appropriately adjusted, apart from economy of testing time. Because of the general shape of the endurance curve, greater consistency is to be expected at the higher values of alternating load.

It should also be noted that Table I can no longer be used directly to indicate the relationship between this new direct gust criterion and the static gust case, since the required number of cycles has been changed as well as the alternating load.

11. Analysis of Statistical Evidence

There remains to be considered the more exact assessment of fatigue properties when gust loading data is available. Such data is obtained from statistical records taken on the particular aircraft type when flying on its normal routes. The subject as a whole lies outside the scope of this paper, but it needs to be considered briefly in order to relate it to the criteria*.

*The analysis of gust data is to be fully described in a paper by J. Taylor, of the R.A.E., probably as an A.R.C. Report.

Essentially the purpose of the systematic analysis of gust records is to obtain a more reliable estimate of the appropriate alternating load, and of the required number of applications, than can be given in empirical formulae for general use. The great majority of gusts lie within a comparative narrow band, say from 5 ft./sec. to 15 ft./sec. An equivalent (or effective)* single gust velocity is determined from the rather complex gust pattern by means of the simple cumulative damage rule. Up-gusts and down-gusts are treated separately and, in the present state of knowledge, it is assumed in applying the formulae that they occur alternately.

The formulae then used take the forms

$$\left.\begin{aligned} A &= \pm K \text{ times the load produced by the effective single gust of equivalent velocity } v \\ N &= LV/m. \end{aligned}\right\} \quad (8)$$

Here, K is a factor of safety for which a value of 1·25 is suggested. The symbol m denotes the average number of miles travelled per gust encountered.

These formulae are similar to those constituting the empirical direct-gust criteria (5), (6) and (7). The only difference is that in the empirical formulae the values of the terms K, v and m are arbitrarily fixed, *i.e.*

In (5), $K = 1{\cdot}00$, $v = 10$ ft./sec., $m = 3$
In (6), $K = 1{\cdot}25$, $v = 8$ ft./sec., $m = 3$
In (7), $K = 1{\cdot}25$, $v = 10$ ft./sec., $m = 6$.

*The adjective "effective" has normally to be used instead of the more appropriate word "equivalent" because this is already in established use for denoting the equivalent ground-level (or "indicated") velocity.

In using the results of statistical analysis it may be necessary to introduce a factor of safety on endurance additional to that on alternating load. It is too early as yet to be definite on this matter, which incidentally does not affect the empirical criteria (*see* Section 9). At present the analysis includes a number of conservative assumptions that give a hidden reserve, and a formal factor of safety is probably not required. Care needs to be taken to ensure that any improvements in technique and extension of theory do not lead to an unintentional lowering of standards.

It must be understood that even the so-called exact analysis still contains a good deal of empiricism. Its main purpose is to make allowance for the different gust conditions which aircraft encounter in different parts of the world and in different operational roles. In spite of the development and expansion of the earlier criteria described here, there are still a number of parameters excluded, and some perhaps which could never be included in any simple criteria for design. The effect of altitude is a good example, since, by flying high, gusts can largely be avoided except during ascent and descent. Gust measurements and their statistical analysis will normally deal adequately with such considerations, at the same time leading to more reliable empirical criteria for general use in initial design.

ACKNOWLEDGMENT

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Liquid Propellant Rocket Motors

by

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PART I—THEORY

B. R. DIPLOCK

1. Introduction

It has been said that a rocket motor is the simplest "prime mover." This is correct in theory, since fundamentally a rocket consists of a chamber containing a gas under pressure, having a nozzle at one end through which the gas expands, forming a propulsive jet. Since the pressure ratio of the rocket is always greater than the critical pressure ratio, the nozzle is invariably of the convergent-divergent or de Laval type in which the velocity is subsonic up to the throat, sonic at the throat and supersonic in the divergent portion.

It is a popular fallacy that a rocket or jet engine obtains a forward thrust by allowing the rearward jet of gas to push against the atmosphere in which it is operating. This is not correct and it can be proved that a rocket will operate successfully, and more efficiently, in a vacuum. The forward thrust is the reaction experienced by the rocket due to rearward ejection of gases at high velocity, thus obeying Newton's Second Law of motion; the thrust is equal to the momentum of the ejected gases relative to the motor.

Momentum is defined as the product of mass and velocity, so that by increasing the exhaust velocity of the gases, the propellant consumption for a given thrust can be reduced. This is the primary aim of rocket designers and improvements can be achieved in several ways.

Notation

T	thrust
dM/dt	mass flow
V_x	exhaust velocity
P_0	chamber pressure
P_x	nozzle exit pressure
P_a	ambient pressure
A_x	nozzle exit area
η	efficiency factor
γ	adiabatic index
G	universal gas constant
θ	combustion temperature
g	gravitational constant
m	mean molecular weight of gases
P_0/P_x	nozzle pressure ratio

Three papers read before the Graduates' and Students' Section of the Society on 4th November 1952.

2. Rocket Performance

The performance index by which rockets are compared is called the "specific impulse" (S.I.) and is defined as the thrust delivered per unit weight of propellants consumed per second. The units are lb./(lb./sec.), the reciprocal of the specific consumption.

The value of S.I. is given by

$$\sqrt{\left[\eta \frac{2\gamma}{\gamma-1}\frac{G\theta}{gm}\left\{1-\left(\frac{P_x}{P_0}\right)^{\frac{\gamma-1}{\gamma}}\right\}\right]}$$

and it can be seen that increases in its value can be obtained by increasing the pressure ratio and temperature, and decreasing the molecular weight of the gases; the effect of changes of γ are very small.

The effect of increasing the pressure ratio on the performance of the motor can be seen in Fig. 1 where the pressure ratio term increases to a maximum when the pressure ratio is infinite, *i.e.* when the exit pressure is zero. This could only occur outside the earth's atmosphere when all the available heat in the jet is converted to kinetic energy, but this is impractical from design considerations since the nozzle would need to have an infinite exit area. For a given exit pressure of say, one atmosphere, it is apparent that the advantage in increasing the chamber pressure above about 35 atmospheres is small. Doubling the pressure in the chamber results in only 6 per cent. increase in specific impulse, and the higher value of pressure demands a more robust and hence a heavier motor. A high chamber pressure is essential for variable thrust motors to maintain a good efficiency under throttled conditions. Current design practice for chamber pressure is 300 to 500 lb./in.^{2}

A high chamber temperature will give high performance, but at the same time it introduces severe chamber and nozzle cooling problems. Regenerative cooling is usually used, in which one of the propellants is circulated round the nozzle and chamber before injection. The mean temperature of the chamber wall must not exceed about 400 to 500°C., and this usually limits the maximum allowable gas temperature to around 2,000 to 2,500°K.

A low molecular weight of the gases is obtained by choosing a propellant combination having a high proportion of H_2O and H_2 in the exhaust, or by having

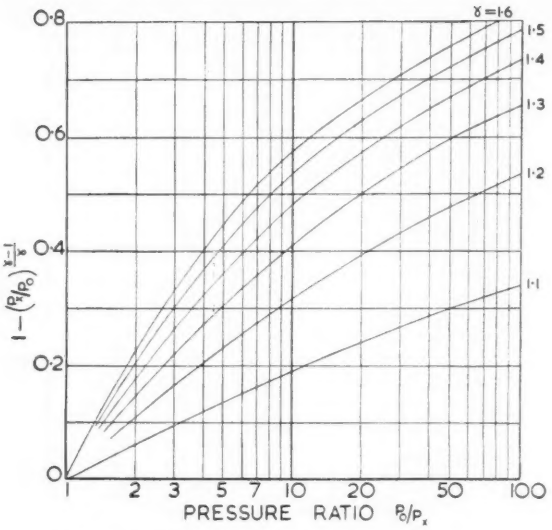

FIGURE 1. Effect of pressure ratio on performance.

a mixture ratio which is slightly on the fuel-rich side of the stoichiometric or chemically correct ratio, since the partially burned products CO and H_2 have lower molecular weights than when burned completely to CO_2 and H_2O.

3. Nozzle Design

The thrust of the motor has been stated to be equal to the mass flow of the gas and the exhaust velocity relative to the motor. This is correct if the gas is expanded in the nozzle to a pressure equal to that of the atmosphere surrounding the motor, and it is known as the "momentum thrust." A second term known as the "pressure thrust" is included when the motor exhausts into an ambient pressure different from the nozzle exit pressure, and equals the product of the difference between the exit pressure and the ambient pressure, and the cross-sectional area of the nozzle exit, *i.e.*

$$T = \frac{dM}{dt} V_x + (P_x - P_0) A_x$$

When the two pressures are equal there is no "pressure thrust" term and the gas is said to be "correctly expanded."

Consider the case of a rocket motor operating at sea level, ambient pressure 15 lb./in.², with a chamber pressure of 300 lb./in.² and a pressure ratio of 20:1. The exit pressure is equal to the ambient pressure and the gas is expanding correctly. If this motor then climbs to 30,000 ft. the atmospheric pressure will fall to about 5 lb./in.², but this change in pressure can have no effect on the gas in the nozzle since it is supersonic, so the exit pressure will remain at 15 lb./in.² The nozzle is then said to be under-expanded and there will be an additional thrust on the motor equal to 10 lb./in.² multiplied by the exit area in square inches.

Therefore, for a constant chamber pressure in the motor, the thrust will increase with increasing altitude, the maximum thrust occurring when the ambient pressure is zero, that is, in space. This is in direct opposition to other forms of aircraft engines which all rely on the presence of an atmosphere for their operation and whose effective thrust decreases with increasing altitude, as shown in Fig. 2. This shows clearly why a rocket motor is the only prime mover suitable for interplanetary flight, since its functioning is entirely independent of external conditions.

Returning to the hypothetical rocket motor at sea level, consider what happens in throttling back to a chamber pressure of 200 lb./in.² The pressure ratio across the nozzle is constant, to all intents and purposes, for a given nozzle configuration, so that the exit pressure will fall, in the same ratio as the chamber pressure, to 10 lb./in.² The nozzle is then "over-expanded" and the pressure thrust term is negative. If considerable over-expansion occurs, the jet will separate from the nozzle wall and the nozzle will not flow full. This means that part of the nozzle is not being used and extra weight is added to the motor for no purpose.

In a rocket designed for a wide altitude range, for example in a missile or interceptor fighter, it is usual to design the nozzle to be correctly expanded at a fairly low altitude, so that it is over-expanded at sea level and under-expanded at high altitudes. For example, the V.2 nozzle was expanding correctly at about 5,000 ft.

Whenever a nozzle is incorrectly expanded some loss of performance results, compared with a nozzle designed to expand the gas correctly over the same pressure ratio.

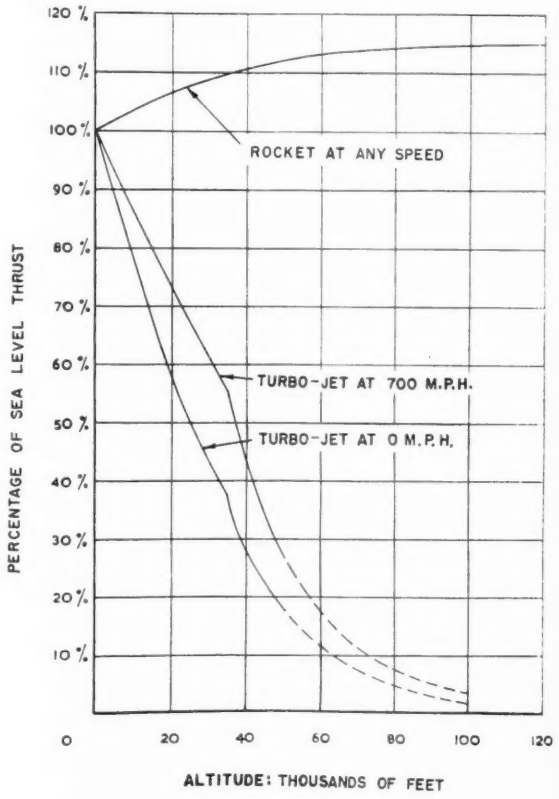

FIGURE 2. Comparative effect of altitude on thrust.

The extent of the performance loss is shown in Fig. 3 which has been calculated for $\gamma = 1{\cdot}2$. The broken line indicates the region where the gas separates from the nozzle wall with the production of oblique shock waves.

The shock wave pattern is often visible in the rocket jet and is made up of alternate areas of slightly compressed and slightly rarefied gas which have different refractive indices, thus producing the characteristic diamond-shaped pattern.

4. Propellant Considerations

The gas in the combustion chamber is really a mixture of gases which are the combustion products of the rocket propellants. The term propellants includes all the liquids that are injected into the combustion chamber, and generally refers to the fuel and the oxidant. In all types of rocket motor the propellants undergo a chemical reaction in the chamber which must be exothermic or energy releasing. This energy is used to raise the combustion products to an elevated temperature and pressure. For a given combination of propellants being injected in a fixed mixture ratio, the temperature attained in the combustion chamber is practically independent of the rate at which the propellants are injected, the mass flow determining the pressure in the chamber. The temperature reached does, in fact, vary slightly with pressure, because of "dissociation." This phenomenon occurs to gases at high temperatures and refers to the splitting of the heavier molecular weight gases into gases having lower molecular weights. For example, CO_2 will dissociate to form CO and O_2, and H_2O will be split into H_2 and O_2, or OH and H_2. The amount of the gas that is dissociated is dependent on the temperature and, to a lesser extent, the pressure of the gas. Very little dissociation occurs below about 2,000° K. and the higher the temperature the greater the dissociation. Increased pressure will tend to reduce the amount of dissociation taking place but the effect is far less than the temperature effect. Dissociation reduces the performance of propellants, because in forming gases of lower molecular weight it absorbs a considerable amount of heat, so reducing the amount of heat available for raising the gas temperature. To offset this reduced temperature to a certain extent, the mean molecular weight of the products is reduced but, taken together, the value of θ/m is reduced, with a consequent loss in performance.

A certain amount of re-association takes place in the nozzle where the temperature of the gas is greatly reduced but, because of the high gas velocity and the short time of stay at the lower temperature, full re-association cannot take place.

The type of propellants used enables the rocket motor to be classified into two main groups:

(*i*) Monopropellant

(*ii*) Bi-propellant.

In the monopropellant system a single liquid is injected into the combustion chamber which burns or decomposes spontaneously, or with the aid of a catalyst. Examples are hydrazine, nitromethane, 80 to 100 per cent. hydrogen peroxide and propyl nitrate.

A bi-propellant system uses two liquids, an oxidiser

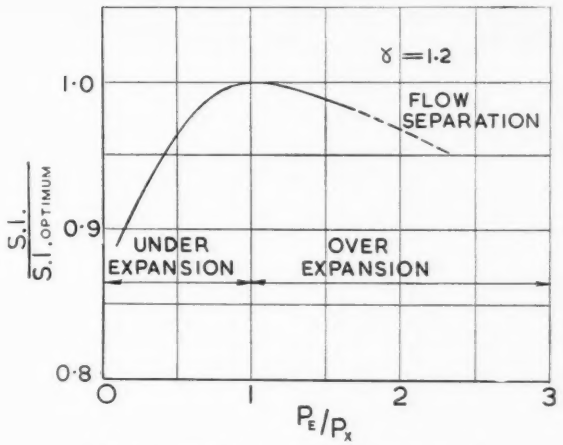

FIGURE 3. Effect of incorrect expansion on S.I.

and a fuel. These liquids are usually injected separately into the combustion chamber in an atomised form and they may, or may not, be self-igniting, or hypergolic. If not, they require an ignition device, but once started the combustion will continue until the flow of propellant ceases. The majority of high performance rocket motors fall into this class. Examples of hypergolic combinations are nitric acid and aniline, and hydrogen peroxide and C-stoff. Non-hypergolic combinations are kerosine or petrol with liquid oxygen, nitric acid or hydrogen peroxide.

A large number of propellant combinations have been examined and their theoretical performance evaluated, and it has been found that there is no combination of readily available propellants which has a vastly superior performance compared with any other. The average specific impulse for present-day bi-propellants is between 200 and 225 sec. with flame temperatures between 2,000 and 3,500° K. It is rarely possible to utilise chamber temperatures above 2,500° K. for any extended burning times, with present chamber materials and cooling techniques, and so the higher specific impulses are not yet attainable.

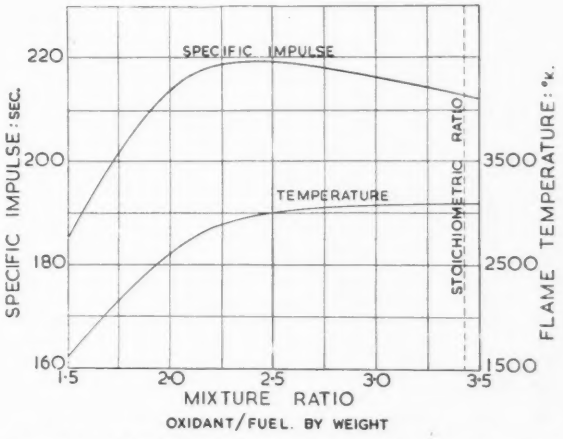

FIGURE 4. Calculated performance of liquid oxygen/kerosine.

The performance curve for a typical combination of propellants is shown in Fig. 4 for a pressure ratio of 20:1. The curve has been calculated for combustion and nozzle efficiencies of 90 per cent. The combination of liquid oxygen and aviation kerosine has the highest performance on a weight basis of any currently used, but unfortunately the peak S.I. of 220 sec. is accompanied by a flame temperature of 3,000°K. This temperature could not be tolerated continuously in a motor at present and so the mixture ratio would have to be altered to reduce the temperature to a more manageable figure. A mixture ratio of 1·8:1 would be suitable, giving a flame temperature of 2,300°K. and an S.I. of 204 sec.

For many aircraft applications the parameter S.I. on a weight basis is not so important as the S.I. on a volume basis, since the available tankage in an aircraft is limited, so use is often made of the term "Density Specific Impulse" which gives the performance of propellants on a volume basis. It is defined as the product of the S.I. (on a weight basis) and the mean specific gravity of the propellants. Using this parameter, the combination liquid oxygen and kerosine is worse than, say, hydrogen peroxide or nitric acid and kerosine, comparing peak values of S.I. For equal flame temperature the denser oxidants are definitely superior.

5. Conclusion

An attempt has been made to show some of the underlying principles involved in the operation of a rocket motor; many more have not even been mentioned. Designers are attempting to make the rocket as efficient as possible, bearing in mind that it could not hope to compete with more conventional motors for continuous running in civil or military aircraft. The rocket designer knows the main advantages of the rocket, high thrust/weight ratio, and high thrust/frontal area ratio, together with its ability to operate at a greater altitude than any other engine, and he is always looking for applications where these things are more important than specific fuel consumption.

PART II—DESIGN

D. L. LOFTS

Any rocket motor can be broken down into three main sections. The combustion chamber, the propellant feed system, and the control and valve system, of which the first two are discussed in this part of the paper.

6. The Combustion Chamber

The basic problem here is to introduce the fuel and oxidant into the chamber, to persuade the fuel to burn in the oxidant, to attain the desired conditions of temperature and pressure, and to expand the products to atmosphere. The chamber design must obviously be favourable to combustion and able to withstand the temperature and pressure conditions.

The combustion characteristics of the chamber depend largely on the time of stay of the propellants. A direct measure of this is the ratio of the volume to the cross-sectional area at the throat. This is known as L^*, the "characteristic length" of the chamber. The time of stay required for the propellants to be completely burned varies with the propellants being used and the combustion chamber pressure, the effect of higher pressure being to cut down the ignition delay and increase the burning rate. Values of L^* that have been used in the past have been about 100 inches. Part I has shown the advantage of using high chamber pressures for variable thrust motors and it is certain that chamber pressures of 400 lb./in.^{2} and higher will be used in the near future. This may also enable L^* to be reduced.

The maximum temperature that can be tolerated in the chamber at present is not much greater than 2,000°C., using a regeneratively cooled chamber. This temperature corresponds approximately to peroxide-kerosine burning at stoichiometric mixture ratio or liquid oxygen-kerosine burning 90 per cent. fuel rich.

These temperature and pressure conditions are more severe than those used in the successful German operational unit, the Walter 109-509. Maximum temperature in that motor was about 1,800°C. and operating pressure 300 lb./in.^{2} Fig. 5 shows the combustion chamber.

The entire chamber is constructed from mild steel, mainly welded sheet. The coolant passage runs the entire length of the chamber, the motor in normal operation being regeneratively cooled by the fuel, although some experimental versions of this motor and other production types were cooled successfully with the oxidant H_2O_2. In the region of greatest heat flow, near the throat, the coolant velocity is increased by the swirls which are cast integral with the light alloy filler block. At the rear end of the motor there is a sliding joint to allow for differential axial expansion of the inner and outer jackets. This differential axial expansion

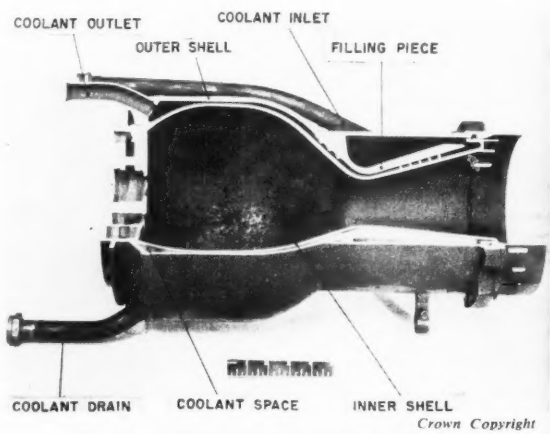

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FIGURE 5. Walter 109-509 combustion chamber.

presents one of the more difficult problems in rocket motor design and the problem gets worse as the operating temperatures and pressures are increased. A sliding joint, as in the Walter motor, could be used but this presents difficulties for more advanced motors. Firstly, there is the problem of providing a suitable seal at the sliding joint to prevent leakage of the high pressure coolant. The Germans used a synthetic rubber seal Buna S., but this was not very satisfactory because of temperature effects on the rubber. When the motor is running the seal can be kept fairly cool by suitable positioning relative to the coolant passage, but on shutting down the cool parts of the motor such as this soak up heat from the hotter parts. Some of the newer synthetic rubbers, particularly of the silicone type, may be satisfactory. Another possibility is some type of bonded asbestos seal, but this would seem to be too rigid to cope with the radial expansion. A much more serious problem is the stresses imposed in the inner shell due to this geometry. Consider first the temperature and stress conditions at the throat of the Walter motor.

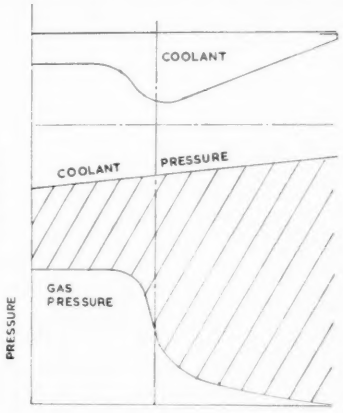

FIGURE 6. The approximate distributions along the chamber and nozzle of the internal gas pressure and the external coolant pressure.

Figure 6 shows the approximate distributions along the chamber and nozzle of the internal gas pressure and the external coolant pressure. The difference in these, shown shaded, gives rise to a compressive hoop stress in the inner shell and, because of the temperature conditions, this is most serious in the region of the motor throat. The mean hoop stress just downstream of the throat is 2·6 tons/in.^{2} The calculated temperatures across the wall are shown in Fig. 7.

Figure 7 shows also the 0·1 per cent. proof stress of a typical mild steel plotted against the wall thickness (*i.e.* against the wall temperature, in effect) and the mean hoop stress. Theory indicates that it is the creep properties of the material that determine the stress distribution and the curve labelled stress distribution has been calculated on this basis. At this mean stress value the wall seems satisfactory.

The sliding joint at the rear of the motor, in conjunction with a high coolant pressure acting over the external surface of the nozzle, produces a high mean axial stress at the throat, of the order of 6 tons/in.^{2} On this basis the design is shown to be marginal. Fig. 8 demonstrates this effect and also indicates the effect of raising the operating motor pressure. There is a

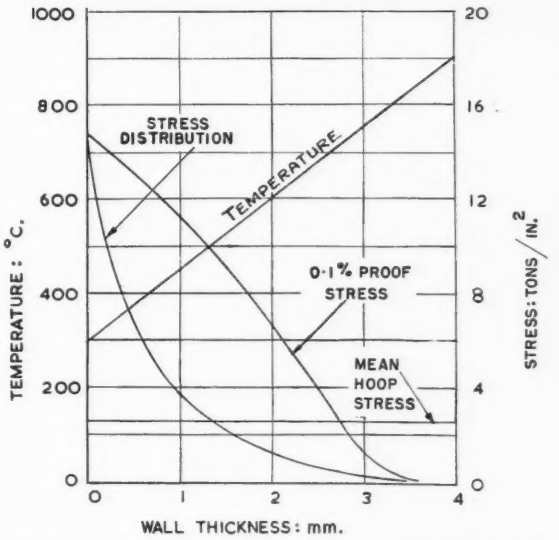

FIGURE 7. Calculated temperatures across the wall and the proof and hoop stresses of a typical mild steel plotted against the wall thickness.

cumulative effect which raises the throat axial stress alarmingly. Firstly, the expansion ratio is higher and the nozzle exit diameter therefore greater. Secondly, the coolant pressure goes up approximately in the same ratio as the combustion chamber pressure. The net result is an excessively high mean axial stress (of the order of 20 tons/in.^{2}).

The obvious way of reducing stresses, that is increasing thickness, cannot be used in this case since wall thickness is one of the most important parameters in heat transfer. In practice, the wall thickness is a compromise between stressing and heat transfer considerations. (It is usually between about 0·08 and 0·15 in. depending on the operating conditions and the material used).

There are three obvious ways of reducing the high axial stresses:—

(*i*) by reducing the outer seal diameter.
(*ii*) by reducing the coolant pressure.
(*iii*) by carrying the load through the outer coolant shell.

Each of these represents a major design change from the Walter motor.

Reducing the seal diameter really means sealing at some point forward of the nozzle exit, and leaving some of the nozzle uncooled. Whether or not this can be done for a continuously operating motor is a matter for conjecture. Reducing the coolant pressure appreciably requires some feed system other than the usual one of supplying the propellants to the injectors by way of the coolant jacket. This means a more complex system. Carrying the loads through the outer shell involves the elimination of the sliding joint, which results theoretically in high stresses due to differential expansion. In practice these may not be severe because of relieving plastic effects. It does not seem possible to predict these effects theoretically and it is really necessary to build

such units and test them. In any case, for a motor required for repeated operations, it is advantageous to be able to remove the outer shell for inspection of the combustion chamber at intervals.

The choice of materials for combustion chambers seems to be rather limited at present. Mild steel is the most commonly used material. This may seem surprising in view of the arduous temperature conditions, but mild steel has a high value of thermal conductivity which has the effect of keeping the hot wall temperature down. It is unfortunate that all the materials with good high temperature properties also have low values of thermal conductivity, but the austenitic stainless steels can be shown to be at least as good as mild steel, especially for the higher combustion chamber temperatures.

If it were not for other considerations mild steel would continue to be used, since it is cheaper and easier to work, but there are good reasons for changing to stainless steel.

As stated previously, the Walter 109-509 motor was regeneratively cooled by the fuel (a mixture of methyl alcohol, hydrazine hydrate, and water), but it is felt that, where possible, kerosine or wide-cut distillate should be used as aircraft rocket motor fuel so as to limit the extra fluids required at the aerodromes to one, *i.e.* the oxidant.

Consider for the three main oxidants, liquid oxygen, hydrogen peroxide, and nitric acid, the quantities of kerosine that are available for cooling. Practical mixture ratios by weight for these three oxidants with kerosine are 1·8:1 for O_2, 3·3:1 for HNO_3 and 9·0:1 for H_2O_2. Only for the O_2 motor is there really a sufficient quantity of kerosine to cool the motor. Since there is insufficient kerosine, the nitric acid and peroxide motors would almost certainly be cooled by the oxidants. Although from the heat transfer point of view both these liquids are good, there are practical difficulties. These are mainly concerned with the behaviour of the oxidant in contact with the surrounding materials. This compatibility problem is different for HNO_3 and H_2O_2. With HNO_3 the problem is essentially the effect of the liquid on the metal. With H_2O_2 it is usually the effect of the metal on the liquid. H_2O_2 readily decomposes into steam and oxygen, when in the presence of a suitable catalyst, with the evolution of a considerable quantity of heat. Unfortunately many metals act as catalysts in this way, including mild steel to some degree. Materials which are compatible with H_2O_2 are pure aluminium, certain aluminium alloys, and high nickel chrome stainless steels. Of these only the stainless steels are suitable for combustion chamber construction. They are also satisfactory for use with concentrated nitric acid. One other great advantage of these steels is their high resistance to scaling at high temperature. Stainless steels of the 12 per cent. nickel, 23 per cent. chromium types will operate with only negligible scaling at temperatures up to about 1,000°C. It is difficult to predict at present what factors will determine the overall life of a rocket motor chamber, but scaling and creep will be of primary importance.

Improved protections, such as overall chromium plating, or ceramic coatings, may make mild steel still the most favourable material.

7. Propellant Feed Systems

Rocket motors are usually either pump-fed or fed from pressurised tanks, but the use of pressurised tanks is only suitable for very short duration motors. Above a certain duration the extra weight of the tanks becomes greater than the weight of a pump system. This duration depends on a number of factors, of which size of motor is probably the most important, but it is usually of the order of 10 to 20 sec.

Rocket motor pumps may be driven either by the rocket propellants or by a separate power supply. If, for example, the motor is to be used as an auxiliary to a gas turbine in the aircraft, the pumps could be driven from the gas turbine. However, this makes the rocket motor dependent on the gas turbine which is not very satisfactory, especially if flight at high altitudes is required. The self-contained rocket motor, therefore, uses some of its propellants for power supply to the pumps. The usual practice is to supply a quantity of propellants to a small gas generator (in effect a small rocket chamber) and the gas products are expanded through a turbine, thus providing power for the pumps. Fig. 9 shows the turbo-pump system for the Walter motor.

The turbine disc in the centre is machined integral with the pump shaft. It is of the impulse type and is driven by the gases from a separate gas generator. The pumps are basically of the double-shrouded centrifugal type, but are each preceded by a screw stage to minimise cavitation. The fuel pump is to the right of the turbine and the oxidant pump to the left.

The first problem to be tackled in the design of such a unit is the production of a suitable gas supply to drive the turbine. One of the more important advantages of using H_2O_2 as the oxidant is that it can be easily decomposed into steam and oxygen, the temperature of the products being approximately 600°C. This is ideal for driving the turbine; the gas is comparatively cool and

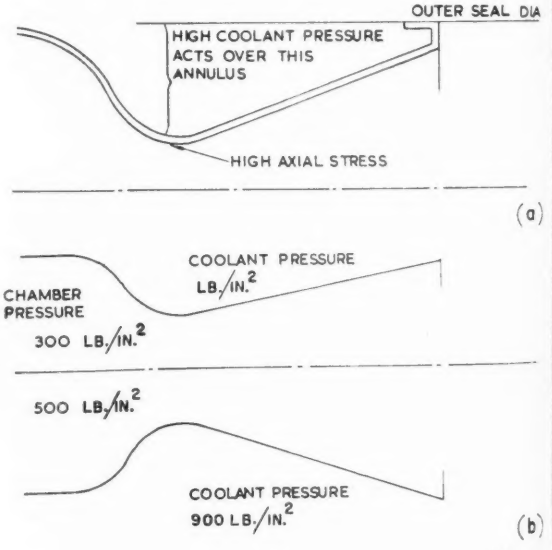

FIGURE 8. Effect of raising the operating motor pressure.

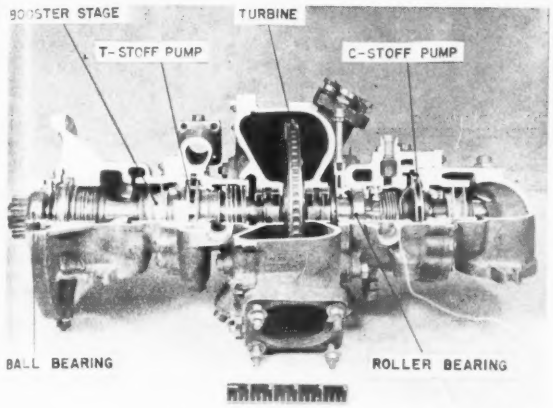

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FIGURE 9. Walter 109-509 turbo-pump assembly.

there is no need to use high creep-resistant material for the turbine blades. This method was used for driving the Walter pumps and the V.2. The V.2 was a liquid oxygen-alcohol motor and the fact that it was considered worthwhile to use a separate liquid for gas generation is significant.

With the pure HNO_3-kerosine, or liquid oxygen-kerosine motors it is necessary to use the main propellants in a gas generator for turbine supply and this may involve combustion difficulties. The maximum gas temperature that can be used for this purpose is approximately 1,000°C. which would mean the use of Nimonic turbine blades (except for short-life motors). To keep the temperature down to 1,000°C. it would be necessary to burn either of these systems approximately 200 per cent. fuel-rich. This would probably result in free carbon in the combustion products, the actual quantities depending on the combustion pressure and the combustion efficiency. Also, there may be difficulty in obtaining smooth combustion at these mixture ratios. One solution would be to burn the propellant at a higher temperature and to cool the products before the turbine by water injection, but whichever system were used the gas generators would have to be cooled. One further problem is ignition, since neither of the systems mentioned is self-igniting.

An idea of flows and powers required may be obtained by considering the design of a turbo-pump system for a 5,000 lb. thrust H_2O_2-kerosine rocket.

For 5,000 lb. thrust the H_2O_2 flow is about 22 lb./sec. and the kerosine 3 lb./sec. For a combustion chamber pressure of 400 lb./in.^{2} the propellants must initially be pumped to about 700 lb./in.^{2} The large flows necessitate centrifugal type pumps and normally a single-stage centrifugal pump would not be used for delivery pressures of this order. However, if low efficiencies can be accepted, this is possible. In fact, efficiencies of the order of 40 per cent. can be achieved with single-stage designs. The efficiency of a single-stage turbine is also low because of the high gas velocity and limited blade velocity and a value of 30 per cent. is not unreasonable. The overall efficiency of the unit therefore is about 12 per cent. The total horsepower required by the pumps is about 150 and the gas horsepower is therefore 450. This requires a flow of H_2O_2 of 1·0 lb./sec., *i.e.* 4 per cent. of the total propellant flow. This justifies to some extent the low component efficiencies of the turbo-pump system.

Conclusion

Rocket motor design is still in its infancy. At present it is necessary to use materials and production techniques that have been developed for other applications; new techniques developed particularly for rocket motors may enable designs to become far more unorthodox.

PART III—DEVELOPMENT

R. A. GRIMSTON

8. Introduction

The development of liquid propellant rocket motors is, to a large extent, specialised by the very nature of the fluids used. The mixture of oxidant and fuel which forms the rocket propellants contains a large amount of energy and is therefore a potentially dangerous combination, but it can be perfectly safe if used with reasonable care and if elementary precautions are taken.

In general the fuels used in rocket motors are those which are already being used in other engines, *e.g.* petrol or kerosine. Both of these are well known and their use no longer causes great concern. There are other fuels which, when mixed with the oxidant they are associated with, are self-igniting, *e.g.* aniline and nitric acid. These are not suitable for use in piloted aircraft, because of the danger which may result from an accident and they will not be discussed further in this paper.

9. Oxidants

Little experience had been gained in handling oxidants until recently and even now there is a lack of knowledge among those not intimately connected with "rocketry."

At present there are three oxidants in general use, hydrogen peroxide, nitric acid and liquid oxygen, each of which requires its own special methods of handling.

With hydrogen peroxide the main problem is in choosing suitable materials for use with it and of maintaining cleanliness in its storage and handling, by keeping matter such as dirt, oil or grease well away from the peroxide. In choosing materials for the construction of parts handling peroxide, the problem is to find those which have no effect upon the oxidant and are unaffected by it, that is, they must be compatible with the peroxide. Any foreign matter, such as dirty rag or wood, may cause the peroxide to decompose with the liberation of sufficient heat to start a fire and storage sites are always kept as free from these materials as possible. If peroxide comes into contact with the skin it causes burns which can be unpleasant, although if the area is quickly washed with water the result is only a mild irritation which soon passes.

The most serious problem with nitric acid is severe corrosion. Most materials are attacked fairly rapidly by it and only pure aluminium or stainless steel is suitable for the storage of the high strength acid. A peculiar feature is that while aluminium is suitable for high strength acid of say, 95 per cent. solution, it is quite unsatisfactory for solutions of about 70 per cent. As the acid often gets watered down in use this raises a problem of its own. Nitric acid can cause severe and toxic burns to the skin and it gives off dangerous fumes. Far more protective clothing is required with this oxidant than the others, including the use of respirators.

Liquid oxygen has several problems peculiar to itself, mainly because of its low temperature. It evaporates at about 180°C. below zero and there is a continuous loss by evaporation from containers. The extremely low temperature leads also to the embrittlement of many metals, while rubber and other seal materials, if dipped into liquid oxygen, become hard and brittle enough to be easily broken. While the spillage of liquid oxygen on the floor does not call for immediate washing away, as it evaporates rapidly, there is a certain fire risk, because of the large quantity of oxygen present.

Hydrogen peroxide or nitric acid, if spilt accidentally, can be diluted by washing with large quantities of water and it is wise to have this readily available on any test or storage site.

10. Development Work

The development of rocket motors can be considered conveniently in two parts. First, the development work before the test-bed stage is reached and secondly, the work connected with the actual running of a rocket motor on the test bed.

The following discussion, while generally applicable to all of the three main oxidants, is based on the author's experience with hydrogen peroxide as the oxidant and kerosine or petrol as the fuel.

11. Materials

A large amount of development work is done on a rocket motor before it reaches the test bed, although the problems met with at this stage are mostly design problems. A good example of design problems is that arising from the materials. Often the only materials which can be used are stainless steel or aluminium but, although these materials may be compatible with the liquids which are being handled, they suffer from severe mechanical pick-up.

A large number of the sliding or rotating parts used in rocket control valves are of stainless steel and it is often impossible to lubricate the parts, as the various available lubricants are not compatible with the propellants under consideration. Even when a compatible lubricant can be found it usually has poor lubricating properties. The most effective solutions to the problem are chrome plating on one of the parts, thus improving the sliding properties of the moving pieces, or the use of plastic materials such as unplasticised poly-vinyl-chloride (P.V.C.) for one of the sliding surfaces. Less effective solutions are the use of different material specifications for the two parts, *e.g.* S.80 and S.110 for stainless steel components, and the careful polishing of the surfaces to reduce their ability to catch in one another. Pick-up of screw threads is best prevented by the use of thin coats of compatible greases, such as some of the silicone base ones.

12. Valves

Valve seats also lead to a lot of development work. If a valve seat may be permitted to leak a little it is possible to make both the valve and its seat in metal and this is also done when, although no leak can be allowed, the valve is subject to high temperatures. In this case the valve and its seat have to be carefully lapped together. A seat which is required to be leak-proof is best made in some non-metallic material, such as rubber or polythene. Usually a metal valve is made with an insert of one of these materials which is either moulded into a groove turned in the metal, or mechanically nipped between two screwed halves of the valve.

13. Seals

Seals are another problem in development work. The most usual materials are rubber, P.V.C., polythene, Fluon or carbon and these are used in seals of the rotating, sliding or static types. Rotating seals find their main application in protecting turbine or pump bearings from the effects of heat or the various propellants. They must seal while the shaft is rotating and when it is stationary.

A popular design in present-day use is one which was shown on the Ministry of Supply stand at the 1952 S.B.A.C. Exhibition. A small impeller rotates with the shaft and in the liquid to be sealed and, by centrifugal action, builds up sufficient pressure at the tip to stop the flow of fluid to the opposite side. When the shaft is not revolving a seal is made by a thin plastic diaphragm bearing against a shoulder on the shaft. This diaphragm lifts under suction as the shaft rotates and this prevents wear of the diaphragm.

Sliding and static seals usually take the conventional form of "U" seals, "O" rings or square-section rings, but these often result in high friction loads, particularly with rocket valves which have to be large to handle the flows required and are subject to high pressures. This leads to hysteresis effects in control valves where a servo pressure opposes a spring, or in similar applications. Little can be done to reduce the friction and the problem is best solved by designing to eliminate as many seals as possible and by providing higher operating loads, thus reducing the percentage friction effect. Fluon is one of the best seal materials as regards friction and is also suitable for use with hydrogen peroxide or nitric acid, but it has little elasticity and therefore careful design is necessary to obtain a good seal. Where the seal is subject to heat, the silicone rubbers are useful and some also resist hydrogen peroxide.

14. Rig Testing of Components

An important part of the development of the rocket is the rig testing of individual components before they

are placed on the complete motor. Because of the potentially dangerous nature of rocket testing, it is essential that everything that can be rig tested before the motor is run should be checked thoroughly. Most of this testing is done by using water in place of the actual propellant and by correcting the test results so obtained. This is much safer and cheaper and allows the test rig to be made from the most suitable materials for the job without any compatibility worries.

In most cases a rocket motor can be built in easy stages and a typical bi-propellant motor using hydrogen peroxide and kerosine as the propellants might be tested as follows.

The control valves and pumps would be tested individually and in groups, using water on the various test rigs. Setting pressures, delivery pressures, pressure drops, flows and other quantities would be measured and corrected to allow for the use of water. The turbine and its steam generator would be tested on a rig with peroxide, the turbine driving a brake or slave pumps working on a closed circuit. This would be done on the rocket test site as peroxide was being used and the various rocket site facilities would therefore be required.

The turbine, steam generator, control valves and pumps would then be grouped together and tested as an assembly. Next, the main peroxide feed from the pumps would be fed into the reaction chamber and cooling tests would be done. Water would almost certainly be used as the cooling medium at first, in the interests of safety; once the tests were satisfactory, the motor would then be cooled with peroxide as in the final version. The last stage would be the injection of fuel into the chamber, starting off with a very weak mixture and running up to the design ratio.

In this way the rocket can be built up gradually stage by stage, testing is made as safe as possible and results to be expected from the next step can be reasonably predicted on the basis of the previous tests.

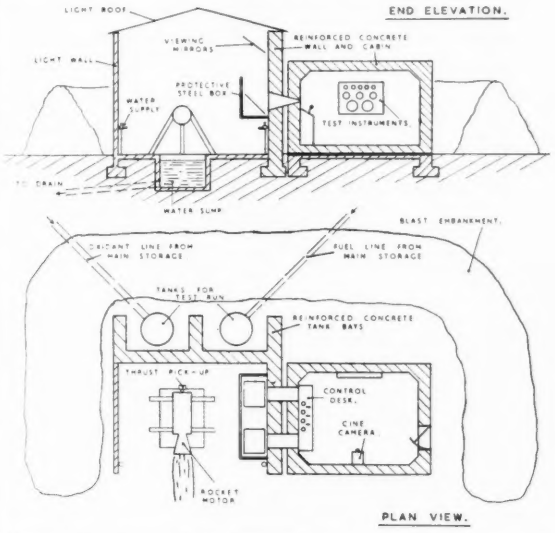

FIGURE 10. Some of the features incorporated in the design of a rocket test bed.

15. The Test Bed

Where the actual propellants are involved the work is done on the rocket test bed, which is built to withstand possible accidents.

There are two schools of thought as to which parts of the test bed should be made strong. One arrangement is to have the actual test cell strong enough to withstand any explosion resulting from an accident, thus confining flying pieces to the test cell; in this way, it is possible to have a fairly light cabin for the test personnel. The other school of thought says that it is the test personnel who are to be protected and that therefore the cabin should be strong. It is then unnecessary, and even undesirable, to make the test cell strong, since it is better not to confine the explosion, and the cell is therefore made relatively weak. The test bed is often surrounded by a blast embankment.

Viewing of the motor on test is by indirect means, such as a mirror system or periscope. When the potential danger is very great, it may even be by wired television, but the expense of this is seldom warranted. Another rule is to keep all the propellants outside the cabin so that the testers are not sprayed with them if a pipe fails. This rule extends even to pipes to pressure gauges, transmitters being used to keep the propellants from reaching the gauges.

To enable immediate washing down of the testers, or the bed, if necessary, there is always a large number of water sources placed about the rocket test site, usually hoses or showers. Because of the need to wash away odd drops of the propellants, the water hoses are one of the most used of the site facilities.

The main propellant storage of a rocket site is always kept at a good distance from the test bed, and the oxidant and fuel stores are kept remote from one another, so as to be safe from the results of any explosion. Other precautions include those designed to keep people not concerned with the test away from the site while the rocket is being fired, *i.e.* gates, warning lights, flags and klaxons (Fig. 10).

The foregoing may lead to the feeling that rocket testing is a highly dangerous business, but this is not so if reasonable care is used. All these precautions are taken, although they will probably never be required.

16. Instrumentation

There are several features of instrumentation peculiar to a rocket site. Many rockets can reach their full thrust conditions within a few seconds of starting which makes it impossible to read numerous gauges, so that it is usually necessary to film the instruments.

The rapid development of the various pressures results in a fairly short life for pressure gauges and these are often protected by the use of restrictors in the gauge feed lines. If the pressures are required accurately over these periods of rapid variation, they may be measured electronically by using a pressure pick-up in which an electrical resistance or capacity is varied by the pressure. The variation is then amplified and passed to a recorder which gives a continuous trace of pressure on films or paper tapes.

Vibration measurement is also done electronically. This is again a measurement of capacity or resistance variation, but it is often convenient to have in the test cabin a gauge calibrated directly in thousandths of an inch vibration.

Temperatures are measured using thermocouples of normal design. There are some troubles in sealing the joints where the thermocouple leads are screwed into the parts being measured, because of the high pressures usually involved and the fluids being handled.

17. Protection of Personnel

Protective clothing of various forms is worn by the test personnel. When handling liquid oxygen the object is to avoid low temperature burns and usually only asbestos gloves and aprons are required. For handling hydrogen peroxide, when the operator must be protected from mild chemical burns or damage to his clothing, he is usually provided with an overall suit of a material such as P.V.C. coated glasscloth, in addition to gum boots and gloves of rubber or P.V.C. Fig. 11 shows an operator wearing this clothing while connecting a filling hose to a peroxide tank.

Burns resulting from nitric acid on the skin are dangerous, as the tissues are damaged and this oxidant requires much more elaborate clothing, including gas masks, to protect the operator from the poisonous fumes which may be given off. When the possibility of the operator being sprayed with propellants is greater than usual, he is also equipped with goggles, face shields or complete hoods.

As a treatment for propellants in the eye, it is a wise precaution to provide eye baths for immediate use. Testers should never work on their own when handling the propellants, since a man with even hydrogen peroxide in his eyes is almost helpless and quite incapable of washing them out.

To keep the propellants away from testers and each other, self-sealing couplings are used whenever a pipe joint has to be broken or on the end of filling hoses.

18. Firing Drill

When a rocket is being fired great care is taken to ensure that nothing can go wrong through any lack of foresight or attention to detail.

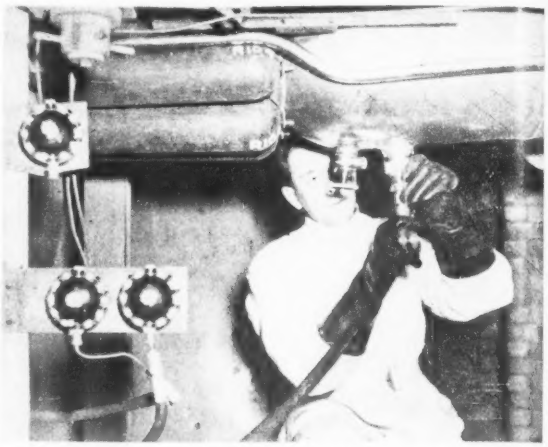

FIGURE 11. Operator in protective clothing connecting a filling hose, with self-sealing coupling, to a peroxide tank.

When the test is about to start everyone not connected with the test leaves the site and then a careful firing drill is carried out. All operations are read out from a chart as they are done and in this way nothing is forgotten and correct sequence of operations is followed. Should any stage in the firing drill be unsatisfactory it can be seen from the appropriate gauges and corrected before anything else is done.

After a large number of firings on the test bed the rocket may be passed for flight testing. This is not such an important stage as with other engines, because the rocket is not so much affected by the atmosphere around. The installation in the aircraft has little or no effect on the rocket performance; for example it is not affected by the configuration of air intakes.

19. Conclusion

While rocket development has its own peculiar problems there are a large number of cases where the troubles are not very different from those experienced with other types of engines. As experience is gained in the work the problems are becoming much easier.

Design of a Simple Electronic Flutter Simulator

by

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(Royal Aircraft Establishment)

SUMMARY:—This paper describes the construction of a simple electronic simulator for the solution of flutter problems in two degrees of freedom. It was intended as a prototype for a much larger machine to solve problems in six degrees of freedom.

Details of the construction and circuits are given, together with some typical solutions obtained on the machine. As a result of the successful operation of this prototype a larger machine in six degrees of freedom has now been built.

1. Introduction

The prediction of flutter of aircraft usually requires the solution of equations of motion in several degrees of freedom. Since the solution is complicated it is usual to limit the analysis to the determination of critical flutter speeds. The problem then reduces to the solution of a determinant, usually complex, of the same order as the number of degrees of freedom. Several ingenious mathematical methods have been evolved to reduce the labour of solving the determinant, but the solution is rarely easy and, in addition, the effect of any variation in the coefficients is often only to be found by the solution of a new determinant.

The large amount of time and skilled effort required to solve flutter equations for many degrees of freedom has become an important factor in determining the extent to which accurate flutter investigations can be made on new aircraft. Any machine, electrical or mechanical, therefore, which would appreciably speed up the solution of these equations and, if possible, increase the range of solutions is to be welcomed.

The electronic simulator described here represents two coupled mechanical oscillations by corresponding coupled electrical oscillations. The electrical circuits are varied step by step to correspond to a step-by-step variation in air speed in the mechanical problem. The flutter solution is determined by the observation of an undamped oscillation in the electrical "degrees of freedom."

It was proposed to use these principles to construct a machine capable of solving problems in six degrees of freedom. Because this application was rather novel, it was decided to build first a simple prototype for two degrees of freedom only, partly to prove the validity of the theory and partly to demonstrate the advantages and explore the limitations of such a machine. The construction and use of this machine is described here. It has been useful in suggesting improvements to the theoretical circuits and in demonstrating the successful application of simulator principles to flutter problems.

Since the construction of this prototype, the larger machine solving problems in six degrees of freedom has been built and is working satisfactorily.

Paper first received February 1952

Notation

A	mechanical inertia coefficient (but *see* Section 2)
A'	aerodynamic inertia coefficient
B	aerodynamic damping coefficient
C	aerodynamic stiffness coefficient
C	capacitor
D	mechanical damping coefficient
E	mechanical stiffness coefficient
G	gain of amplifier
l	aerodynamic lift derivative
l_θ	flexural stiffness
m	aerodynamic moment derivative about wing leading edge
m_θ	torsional stiffness
R	resistance
S	voltage factor
t	time
V	voltage
v	air speed coefficient
V_a	reference air speed
x	displacement in a degree of freedom
z	vertical displacement of wing leading edge
α	angular displacement of wing
τ	time constant
ω	phase angle
Ω	ohm
$k\Omega$	kilohm
$M\Omega$	megohm

2. The Flutter Problem

The mechanical oscillation of an aerofoil in an air stream in the degree of freedom "x" may be written

$$(A+A')\ddot{x}+(Bv+D)\dot{x}+(Cv^2+E)\,x=0$$

with the usual assumptions that aerodynamic terms of order higher than two may be neglected.

A, A' are the mechanical and aerodynamic inertia

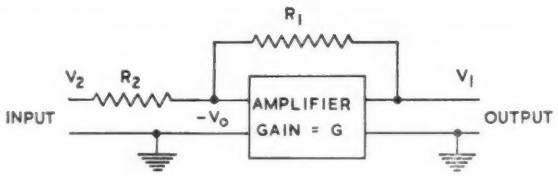

FIGURE 1. Amplifier with resistance feed-back.

coefficients, D, B the corresponding damping coefficients, E, C the stiffness coefficients, and v is proportional to the air speed.

Since the aerodynamic inertia is, by definition, invariable with flight speed it may be included for simplicity in the mechanical inertia and A will be used to denote the sum of mechanical and aerodynamic inertia coefficients.

Thus the equations of motion in two degrees of freedom are

$$A_{11}\ddot{x}_1+(B_{11}v+D_{11})\dot{x}_1+(C_{11}v^2+E_{11})x_1=0 \qquad (1)$$

$$A_{22}\ddot{x}_2+(B_{22}v+D_{22})\dot{x}_2+(C_{22}v^2+E_{22})x_2=0 \qquad (2)$$

When the cross-coupling terms are added they become

$$A_{11}\ddot{x}_1+(B_{11}v+D_{11})\dot{x}_1+(C_{11}v^2+E_{11})x_1+A_{12}\ddot{x}_2+ +(B_{12}v+D_{12})\dot{x}_2+(C_{12}v^2+E_{12})x_2=0 \quad . \qquad (3)$$

$$A_{21}\ddot{x}_1+(B_{21}v+D_{21})\dot{x}_1+(C_{21}v^2+E_{21})x_1+A_{22}\ddot{x}_2+ +(B_{22}v+D_{22})\dot{x}_2+(C_{22}v^2+E_{22})x_2=0 \quad . \qquad (4)$$

These equations are more complete than is usually necessary, but in order to make the simulator as general as possible, all terms are included. x_1 and x_2 are the displacements in their respective degrees of freedom, and the coefficients, A, B, C, D, E represent the structural and aerodynamic characteristics of the aircraft or design under investigation.

In the British method of solution of practical flutter problems it is usual to treat the coefficients B, C as invariable with respect to speed and frequency and this approach will also be made here. However, as will be seen later, the effect of varying any coefficient is easily found and a more exact solution can be obtained by a method of successive approximations.

The method of solution will normally be by variation of the air speed coefficient v, although in some cases, notably at speeds near that of sound where the structural stiffness for a given flutter speed may be required, the solution may be by variation of certain coefficients.

3. The Electronic Representation of the Problem

3.1. AMPLIFIER WITH RESISTANCE FEED-BACK

Consider the circuit shown in Fig. 1. A direct coupled amplifier of gain G has a resistance feed-back R_1. The input is supplied from a voltage V_2 through resistance R_2. Then, if the input impedance of the amplifier is infinite, the total current flow from V_1 and V_2 to the amplifier input must be zero, *i.e.*

$$\frac{V_1+V_o}{R_1}=-\frac{V_2+V_o}{R_2}$$

and since $V_1=GV_o$,

then $$\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_1}{G}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)=0.$$

If G is large,

$$\frac{V_1}{R_1}+\frac{V_2}{R_2}=0,$$

which represents the equation

$$A_1x_1+A_2x_2=0,$$

where $A_1\propto\frac{1}{R_1}$, $A_2\propto\frac{1}{R_2}$.

In particular, if $R_1=R_2$

then $V_1=-V_2$.

Thus an amplifier may be used to reverse the sign of a variable.

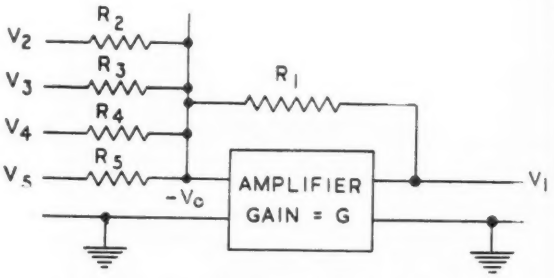

FIGURE 2. Input from several supplies in parallel.

When the input consists of several supplies in parallel (Fig. 2),

$$\frac{V_1}{R_1}=-\left(\frac{V_2}{R_2}+\frac{V_3}{R_3}+\frac{V_4}{R_4}\ldots\ldots\ldots\ldots\right),$$

which represents the equation

$$A_1x_1+A_2x_2+A_3x_3+A_4x_4\ldots\ldots\ldots\ldots=0.$$

In this way the terms in equations (3) and (4) can be added together and equated to zero.

The inverse proportionality of feed-back resistor to coefficient makes representation difficult. If, however, only a fraction, S_2, of the voltage V_2 were supplied to R_2, then

$$A_2\propto\frac{S_2}{R_2}$$

so that, if R_2 is now regarded as fixed and S_2 adjustable, the coefficients A_2, A_3, can be represented directly. Where the feed-back from the output voltage V_1 (Fig. 1) is through a resistance, the same system can be used to represent A_1 directly. Variation of S_1 can be obtained from a tapped potentiometer from V_1 to earth. If the tappings are in tenths of V_1, and two tappings S_{a1}, S_{b1},

are applied through resistances R_1, $10R_1$, connected in parallel to the input of the amplifier (Fig. 2), then

$$V_1\left(\frac{S_{a1}}{R_1}+\frac{S_{b1}}{10R_1}\right)+V_2\left(\frac{S_{a2}}{R_2}+\frac{S_{b2}}{10R_2}\right)=0,$$

or with $R_1=R_2$

$$V_1(S_{a1}+0{\cdot}1S_{b1})+V_2(S_{a2}+0{\cdot}1S_{b2})=0.$$

Thus $$A_1x_1+A_2x_2=0,$$

with the coefficients A_1, A_2 adjustable to two places of decimals, with a maximum value of 1·10.

In equations (3) and (4) the variables $\dot{x}$ and x are associated in some terms with v and v^2 respectively where v is proportional to the air speed in the flutter problem.

An amplifier with resistance feed-back (Fig. 1) modified so that the input from V_2 is through a potentiometer of setting S_2 and the feed-back resistor is variable and equal to S_2R_2, gives

$$\frac{S_2V_2+V_o}{R_2}+\frac{V_1+V_o}{S_2R_2}=0.$$

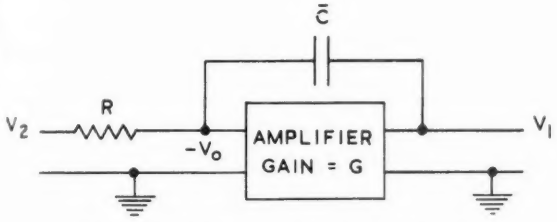

FIGURE 3. Amplifier with capacity feed-back.

With the assumption that the amplifier gain is large,

$$V_1=-S_2^2V_2,$$

or if $$S_2=v$$

$$V_1=-v^2V_2,$$

so that if V_2 is representing x, then V_1 represents v^2x.

Further, if the feed-back resistance is fixed at a value equal to R_2 then

$$V_1=-vV_2$$

or, if V_2 now represents $\dot{x}$, then V_1 represents $v\dot{x}$.

3.2. AMPLIFIER WITH CAPACITY FEED-BACK

If the feed-back is through a capacity $\bar{C}$ instead of a resistance, as in Fig. 3, then

$$\bar{C}\frac{d}{dt}(V_1+V_o)=\frac{-(V_2+V_o)}{R},$$

or with $$V_o=\frac{V_1}{G}$$

$$R\bar{C}\dot{V}_1\left(1+\frac{1}{G}\right)+V_2+\frac{V_1}{G}=0.$$

If V_1, V_2 are of the same order and G is large,

$$R\bar{C}\dot{V}_1+V_2=0,$$

or $$A\dot{x}_1+Bx_2=0.$$

With $R\bar{C}=1$, then $A=B$ and V_1 is the integral of V_2 and the unit acts as an integrator.

3.3. REPRESENTATION OF A ONE-DEGREE-OF-FREEDOM EQUATION

The representation of the one-degree-of-freedom equation (equation (1)) is now considered. Fig. 4 shows five amplifiers coupled together, one as a summing unit, two as integrators, and two more representing the effect of air speed. Considering the output of the first amplifier, V_1, as representing $\ddot{x}_1$, the output of the second amplifier, V_2, is the integral of V_1, *i.e.* $\dot{x}_1$ (if the time constant $R\bar{C}=1$), and similarly $V_3=x_1$. With air speed selectors Type A (potentiometer) and selector Type B (variable feed-back resistor) mechanically coupled and set to correspond to the air speed v, the outputs of Amplifiers 4 and 5 are $v\dot{x}_1$, v^2x_1 respectively. The outputs of all five amplifiers are taken to the input of Amplifier 1, through potentiometers which can be set to multiply these outputs by the appropriate coefficients A_{11}, B_{11}, C_{11}, D_{11}, E_{11}, and with Amplifier 1 as a summing amplifier, the representation of the equation is complete.

If an electrical disturbance is introduced into this circuit it will respond in a manner identically equivalent to that of the simulated mechanical system when similarly disturbed.

3.4. EXTENSION TO TWO DEGREES OF FREEDOM

It has been shown how the simulator can represent an oscillation in one degree of freedom:—

$$A_{11}\ddot{x}_1+(B_{11}v+D_{11})\dot{x}_1+(C_{11}v^2+E_{11})x_1=0.$$

A second unit can be used to represent the independent oscillation

$$A_{22}x_2+(B_{22}v+D_{22})\dot{x}_2+(C_{22}v^2+E_{22})x_2=0.$$

In order to represent the flutter equations it is

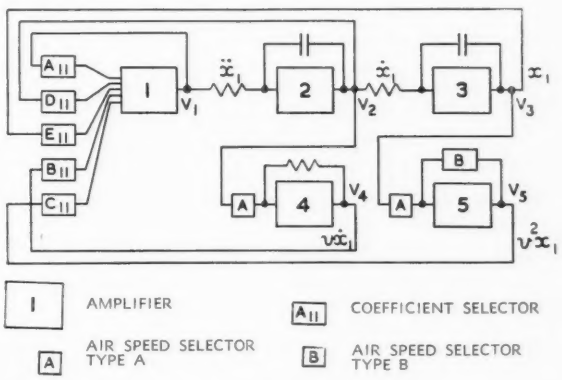

FIGURE 4. Representation of one-degree-of-freedom equation.

necessary to add the cross-coupling terms in equations (3) and (4). To do this extra electrical couplings and potentiometer units must be added so that each amplifier output in Unit 1 is coupled to the input of Unit 2, in addition to being coupled to the input of Unit 1. Similarly for the output of the amplifiers of Unit 2.

The complete circuit for two degrees of freedom with cross couplings is shown in Fig. 5.

3.5. PUSH-PULL AMPLIFIER

So far only single-sided direct-coupled amplifiers have been described and they are known to be liable to drift with time, making more difficult the operation of the simulator using them. In addition, since the coefficients of the flutter equations may, in general, be either positive or negative, a large number of amplifiers would be needed to reverse the sign of a coefficient (*see* Section 3.1).

Both these problems are simplified by the use of push-pull amplifiers. Here drift is greatly reduced and the reversal of sign is obtained simply by interchanging the push-pull connecting leads.

4. Detail Design of the Flutter Simulator

4.1 AMPLIFIER

Since on this prototype machine an overall accuracy of only one per cent. was aimed at, it was decided that amplifiers of quite low gain would be adequate. A single stage push-pull amplifier with two CV 1091 valves is used. The circuit is shown in detail in Fig. 6. High stability carbon resistors are used for the input chain to the valve grids, the values on each side of the chain being matched to 0·1 per cent. The remainder are selected 20 per cent. tolerance carbon resistors.

Relative to the voltage level at the input terminals the power supply was + 150 volts and − 150 volts, the anodes were at zero potential (adjustable), the grids and cathodes at − 50 volts. The mean potential difference across the valve was thus 50 volts. With ± 20 volts swing on the anode outputs there was no chance of excessive overload of the system before the valves ceased to conduct.

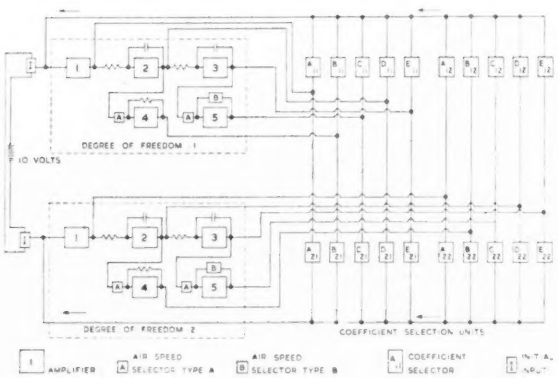

FIGURE 5. The complete circuit for two degrees of freedom with cross couplings.

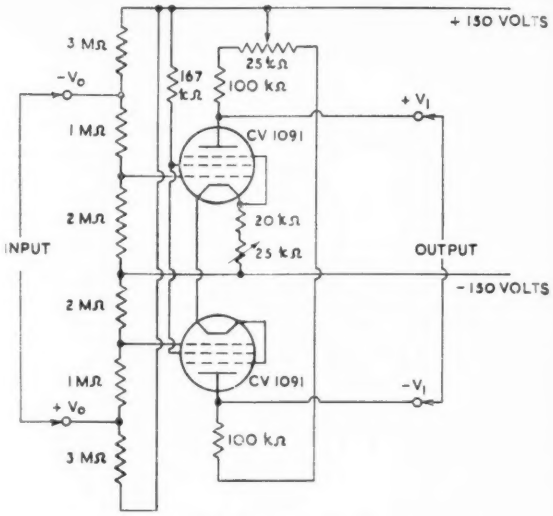

FIGURE 6. Amplifier circuit on prototype machine.

The gain of this amplifier with a load of 100 kΩ was about 50 and, since this gain would have given errors of 2 per cent. and more, it was decided to use a form of positive feed-back to give an effectively larger gain with correspondingly less error. This positive feed-back is shown diagrammatically in Fig. 7 and is represented by the resistance R'. With an effective push-pull input impedance of 3 MΩ, and expressing the current flow to point X (Fig. 7) as zero

$$\frac{S_1V_1+V_0}{1}+\frac{S_2V_2+V_0}{1}+\frac{S_3V_3+V_0}{1}\cdots\cdots\cdots\cdots+$$
$$+\frac{V_0+V_0}{3}+\frac{-V_1+V_0}{R'}=0,$$

$$i.e.\qquad \sum_1^n S_rV_r+(n+0{\cdot}67)V_0=\frac{V_1-V_0}{R'}.$$

Without positive feed-back the error term would be

$$(n+0{\cdot}67)V_0.$$

Adjusting R' to eliminate this error

$$R'=\frac{G-1}{n+0{\cdot}67}\qquad \text{where } G=\frac{V_1}{V_0}.$$

For a summing amplifier with 11 inputs

$$R'=\frac{G-1}{11{\cdot}67}.$$

For an integrating amplifier

$$R'=\frac{G-1}{1{\cdot}67}.$$

With an integrating amplifier there is a further error since the time constant τ is given by

$$\tau=R\overline{C}\left(1+\frac{1}{G}\right)$$

and not

$$\tau=R\overline{C}.$$

So. to obtain a time constant of one second

$$R\bar{C} = \frac{G}{G+1} \simeq 0\,98\,.$$

In practice the resistances and capacities were matched to give a value of $R\bar{C} = 0{\cdot}98 \pm 0{\cdot}01$.

The output from each amplifier is connected to a voltmeter on the left hand side of the control panel (Fig. 8). These meters are used for amplifier adjustment and also, to observe the electrical oscillation which corresponds to the structural oscillation occurring after a disturbance.

4.2 COEFFICIENT SELECTION UNIT

The coefficients A, B, C, D, E in equations (3) and (4) have to be readily and accurately variable. This is done in the electrical circuits by varying the proportion of the output voltage from each amplifier which is to be fed back into the summing amplifiers. This requires a chain of resistors across the output which can be tapped in steps of 0·1 of the output voltage and, since push-pull inputs and outputs are used, the chains are split into two, one half being a mirror image of the other (Fig. 9). Considering only the positive half of the chain, it will be seen that the tapping lines containing the two resistors 1 MΩ and 10 MΩ can be adjusted so that a definite fraction of the output voltage V_1 can be placed across each of these resistors. If the 1 MΩ tapping line is placed at $0{\cdot}8V_1$ and the 10 MΩ tapping line at $0{\cdot}4V_1$, then the currents flowing through each resistor are $0{\cdot}8V_1$ micro-amps and $0{\cdot}04V_1$ micro-amps, giving a total of $0{\cdot}84V_1$ micro-amps. A coefficient 0·84 has thus been represented to two decimal places. In addition a change-over switch is provided so that the signs of the input leads can be reversed. In this way a coefficient of $\pm 0{\cdot}84$ can be represented.

The resistors in the potentiometer chains are of the order of 20 kΩ, each value being adjusted, within 0·5 per cent., such that, with the 1 MΩ tapping line in any position, the current in the resistor corresponds exactly to its decade setting. Consequently, there are some small errors in the current passing through the 10 MΩ resistor but these are never more than 0·5 per cent. of the full current through the 1 MΩ resistor.

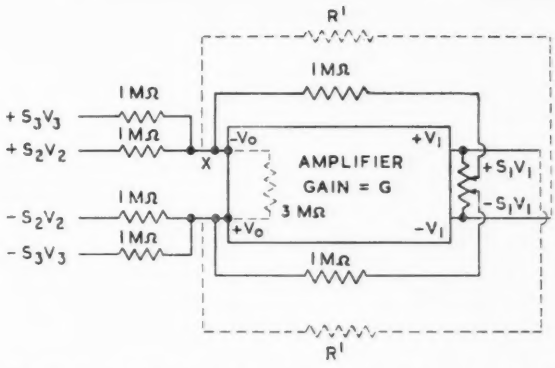

FIGURE 7. Positive feed-back used to give a larger gain and smaller error.

The controls for these coefficient selection units are installed on the right hand side of the control panel (Fig. 8).

4.3. AIR SPEED SELECTION UNITS

Two types of air speed selection unit are required. Type A is similar to the coefficient selection unit, the only difference being the omission of the change-over switch, since negative air speeds are not required.

Type B is shown in Fig. 10. Again two decade controls are supplied, one switching in resistors of 100 kΩ and the other resistors of 10 kΩ, the resistors being chosen to an accuracy of 0·5 per cent. The unit is again capable of giving a push-pull input to an amplifier from the push-pull output voltage.

If the setting of the first switch is n and that of the second is m then the total resistance per side is $(100n + 10m)$ kΩ or $(0{\cdot}1n + 0{\cdot}01m)$ MΩ. The decade switches of Type B are mechanically coupled to those

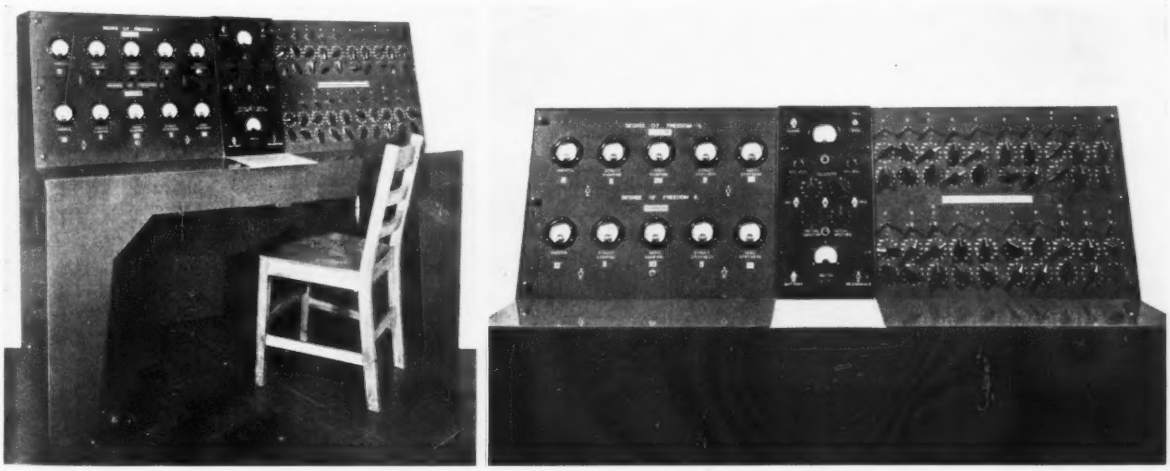

FIGURE 8. Electronic flutter simulator.

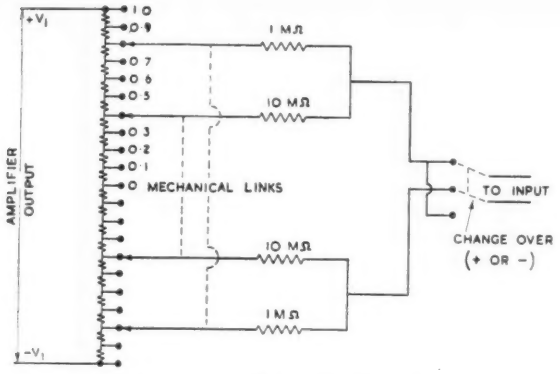

FIGURE 9. Coefficient selection unit.

of Type A such that when the current flow in Type A is $(0{\cdot}1n+0{\cdot}01m)\ V_1$ micro-amps, then the resistance in Type B is $(0{\cdot}1n+0{\cdot}01m)$ MΩ.

Referring to Fig. 4, the input to Amplifier 4 is supplied from the output of Amplifier 2 through a Type A unit. If $0{\cdot}1n+0{\cdot}01m=v$ where v is proportional to the air speed in the flutter problem then, with the output of Amplifier 2 corresponding to $\dot{x}_1$, the output of Amplifier 4 corresponds to $v\dot{x}_1$.

The input to Amplifier 5 is supplied from the output, V_3, of Amplifier 3, representing x_1, by another Type A unit which is mechanically coupled to the first Type A unit and also to a Type B unit. The Type B unit connects the output of Amplifier 5, V_5, to its own input. Neglecting errors due to the finite gain of the amplifier, which are corrected by positive feed-back,

$$\frac{vV_3}{1}+\frac{V_5}{v}=0 \qquad \text{or} \quad V_5=-v^2V_3\,.$$

By changing over the push-pull connections,

$$V_5=+v^2V_3=v^2x_1\,.$$

The two decade controls for air speed are in the centre of the control panel (Fig. 8).

4.4. INITIAL INPUT UNIT

In order to start the electrical oscillation it is necessary to give an initial disturbance to the electrical circuit—the equivalent of a gust or sudden displacement of a control surface on the equivalent full-scale aircraft. This initial disturbance is supplied by applying a fixed voltage from a battery through a potentiometer to the input of each summing amplifier. In this manner a given disturbance can be applied to either or both degrees of freedom for a given period of time. A battery supply of 10 volts is used (Fig. 5).

4.5. LOCKING UNIT

After a particular response has been observed, it is obviously desirable to be able to stop any remaining motion and return the simulator to its initial condition. This is done by short-circuiting the push-pull inputs of each of the amplifiers. Each degree of freedom is treated separately by using a 5-way relay, battery-operated, for each set of five amplifiers. In this manner each degree of freedom can be locked independently and the simulator ceases to represent the flutter equations.

4.6. POWER SUPPLY UNIT

The power supply for the ten amplifiers is a conventional "radio-type" unit (Fig. 11). No special precautions have been taken to stabilise or smooth the D.C. output of the rectifier. 6·3 volts A.C. is used for the valve heaters, the H.T. current is 50 milli-amps at 300 volts and the total consumption is 50 watts.

5. Methods of Operation

Having obtained the flutter equations in the form of (3) and (4), the equations must be adjusted so that none of the coefficients exceeds the value 1·10 and yet, to preserve the accuracy, they are all as large as possible. This can be done by altering the frequency scale to give a circular frequency of approximately unity, adjusting the scale of displacement in each degree of freedom so that the displacements are of the same order, and choosing a reference air speed, V_a, where air speed$=vV_a$, such that v does not exceed 1·10 during investigation of the problem. This manipulation takes only a few minutes and can be made in the earlier stages of a flutter calculation without any additional effort.

After adjustment of the problem the coefficients A_{11} etc. can be put on the machine. With $v=0$ and the second degree of freedom locked, an oscillation, as shown by the meters, can be started in the first degree of freedom by means of the initial disturbance mechanism. This oscillation represents the actual oscillation in the corresponding assumed mode in still air. This test can be repeated with the first degree of freedom locked and the second unlocked.

With both unlocked, the motion represents the natural oscillations of the corresponding structure in the two degrees of freedom.

If now, the air speed coefficient v is increased from zero, the oscillation ensuing after a disturbance will

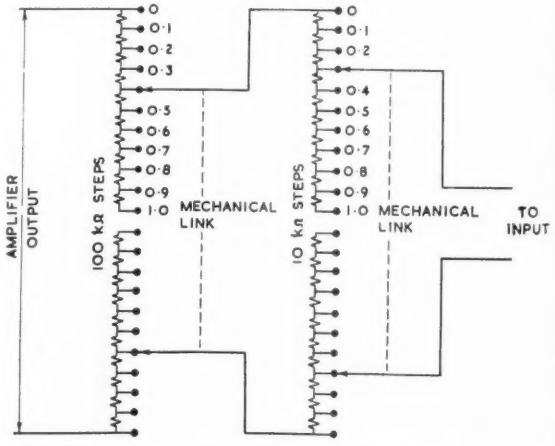

FIGURE 10. Type B air speed selection unit.

represent the motion of the aircraft in the two degrees of freedom after a disturbance in flight. This motion will normally be damped, but if v is increased sufficiently the motion will become first sinusoidal in character and then, at higher values of v, will be divergent and oscillatory. The value of v where the motion is oscillatory and neither damped nor undamped corresponds to the critical flutter speed, which is given by vV_a. If the motion is divergent but non-oscillatory, then a divergence speed (vV_a) has been found. This divergence speed is not necessarily the true divergence speed since oscillatory aerodynamic derivatives will have been used in setting up the problem.

The frequency of the motion is the flutter frequency, when the arbitrary factors discussed have been re-inserted. The amplitudes and phase difference of the two degrees of freedom can readily be seen from observation of the meters.

An alternative method of solution is to fix the air speed coefficient (at, say, the top speed of the aircraft) and vary one or more of the coefficients A_{11}, etc., until the critical solution is obtained. In this way, the margin of safety in mass balance of a control surface can be obtained. This method is also to be recommended for investigations at high Mach number where the usual requirement that the flutter speed should be well above the top speed of the aircraft may become meaningless, since the aerodynamic derivatives are changing rapidly with Mach number. Here a margin of positive damping (given by D_{11}, D_{12}, D_{21}, D_{22}) at a fixed speed or Mach number may be a better measure of the safety of the aircraft at that speed.

6. Example of Flutter Solutions Obtained with the Simulator

In order to illustrate the type of problem which can readily be solved on the simulator, and the accuracy of the machine, two examples are given.

6.1. Effect of Damping or Excitation on Flutter Speed and Frequency

The coefficients D_{11}, D_{12}, D_{21}, D_{22} can be interpreted as representing structural damping. They do not usually appear in numerical flutter calculations because they may increase the difficulty of solution considerably and their exclusion in any case generally represents a (small) margin of safety. With the simulator, however, the effect of structural damping can easily be investigated.

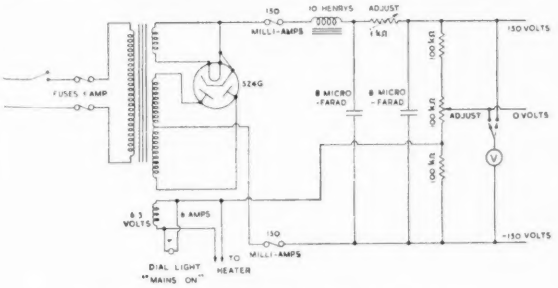

FIGURE 11. The "radio-type" power supply unit.

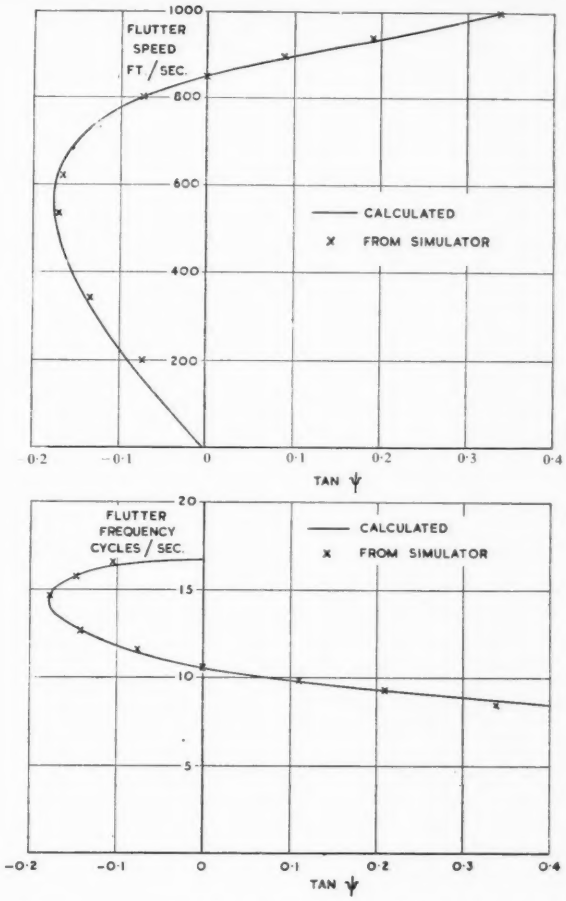

FIGURE 12. Comparison of results by calculation and by use of the simulator.

A simple and representative way of finding the effect of structural damping by calculation is to put the factor $e^{i\psi}$ into the stiffness terms $E_{11}x_1$ and $E_{22}x_2$. This phase shift is equivalent to adding direct damping, represented by D_{11}, D_{22}, into each degree of freedom, the amount being proportional to the direct stiffness in each degree of freedom. The equations taken were:—

$$0{\cdot}99\ddot{x}_1 + 0{\cdot}36\,\dot{x}_1 v + 0{\cdot}14x_1 v^2 + 0{\cdot}14x_1 e^{i\psi} + 0{\cdot}32\ddot{x}_2 - + 0{\cdot}36\dot{x}_2 v + 1{\cdot}09x_2 v^2 = 0$$

$$0{\cdot}90\ddot{x}_1 + 0{\cdot}70\,\ddot{x}_2 + 0{\cdot}54\,\dot{x}_2 v + 1{\cdot}10x_2 e^{i\psi} = 0\,.$$

V_a was 1,000 ft./sec. and the frequency scale factor was 20π, *i.e.* a frequency of 10 cycles per second was reduced to a circular frequency of one.

The solutions of this problem for various values of $\tan\psi$, representing the degree of structural damping, were obtained both by calculation and by use of the simulator.

The results are shown in Fig. 12 for both positive and negative values of $\tan\psi$. The positive values correspond to positive damping. The negative values may be interpreted as a suitable excitation force, as in flight resonance testing technique.

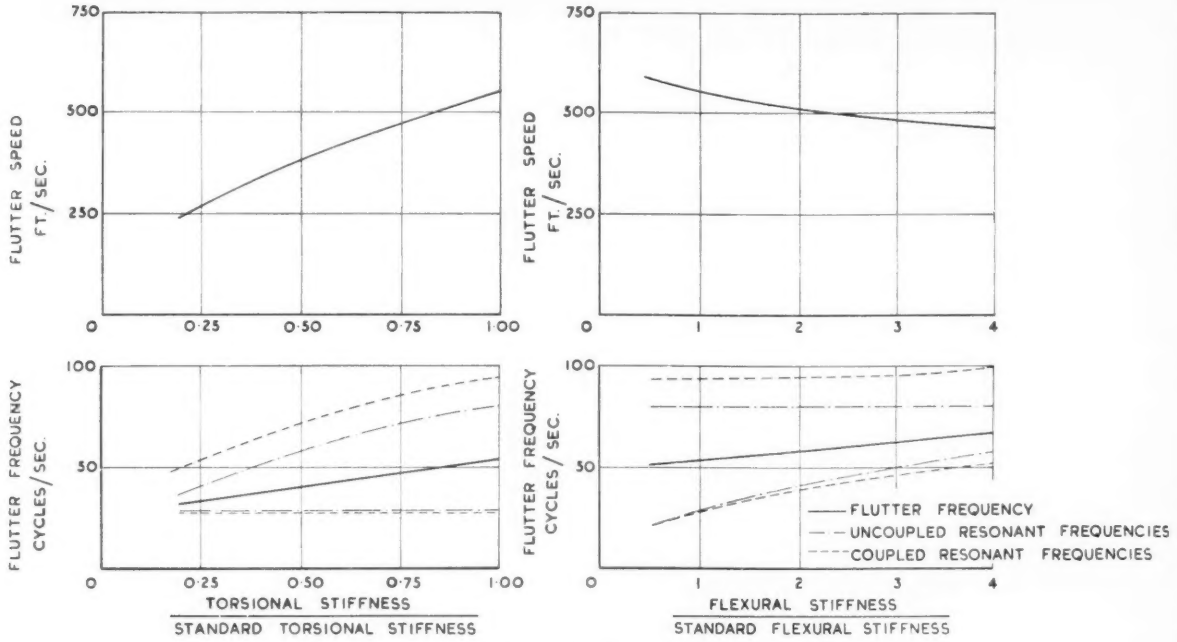

FIGURE 13. Results showing effect of flexural and torsional stiffness.

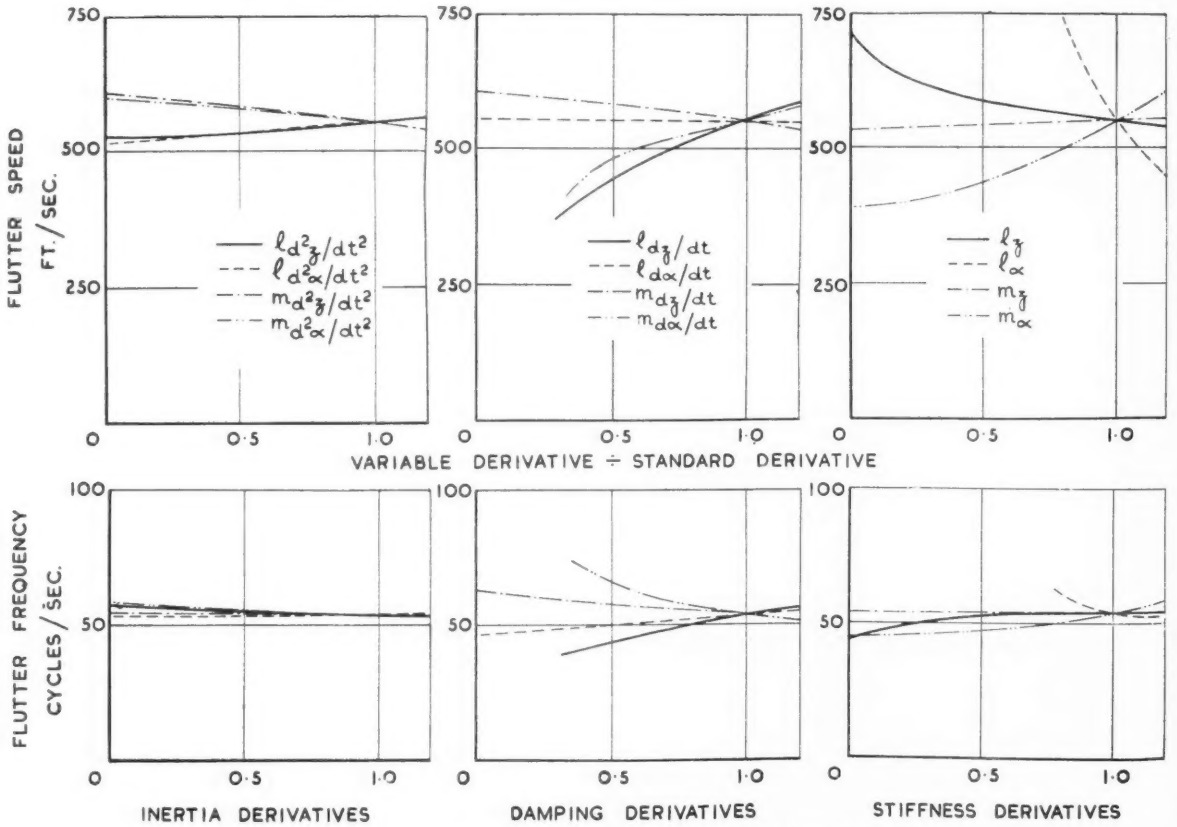

FIGURE 16. Results showing effect of inertia, damping and stiffness derivatives.

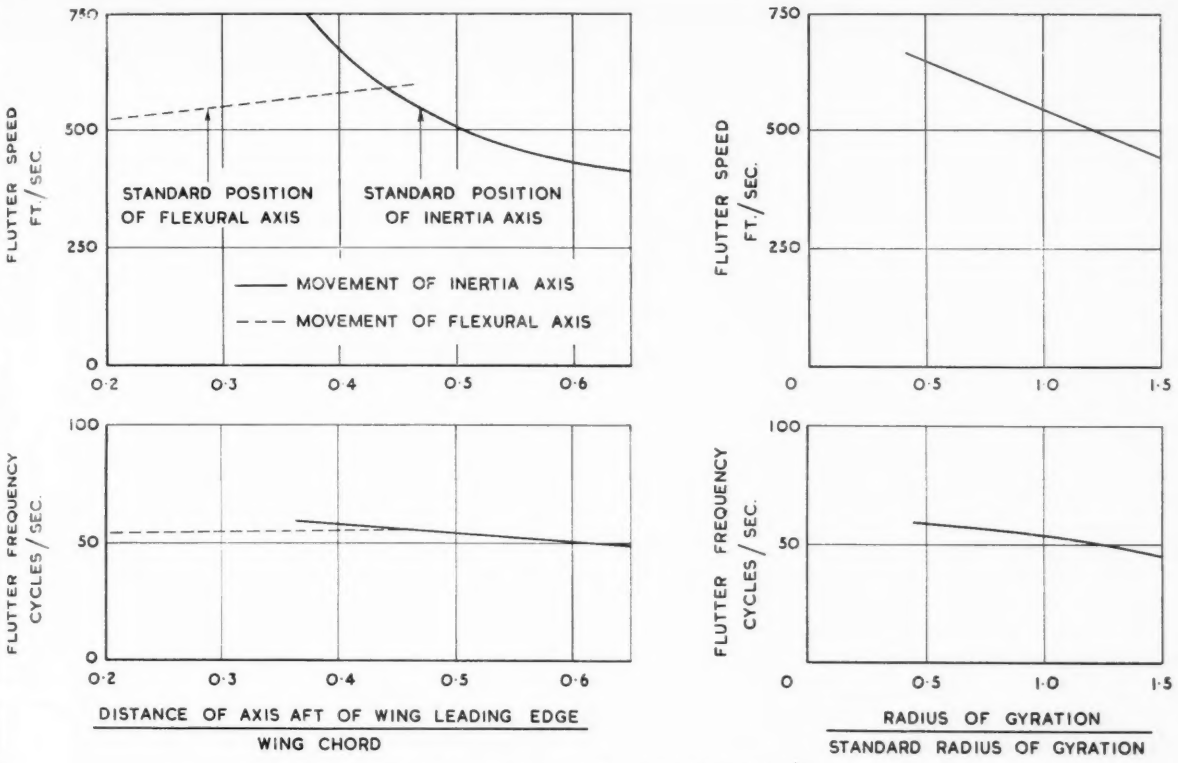

FIGURE 14. Results showing effect of positions of flexural and inertial axes and of radius of gyration.

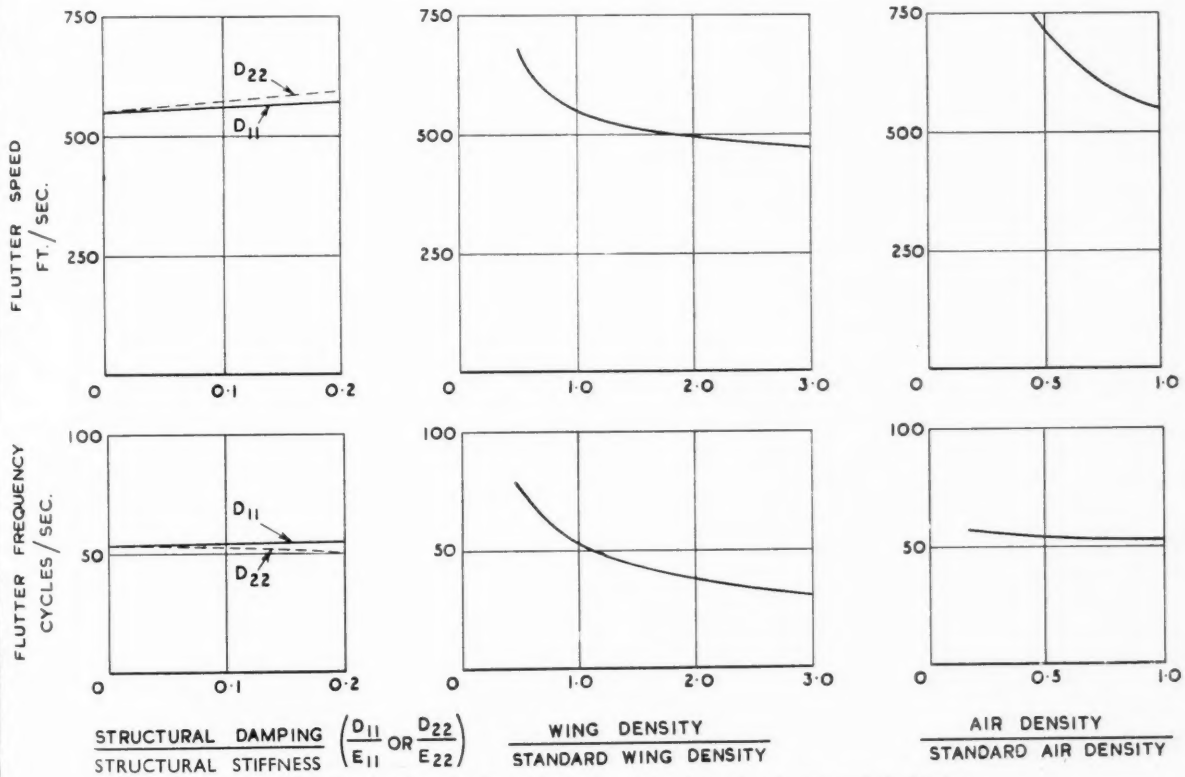

FIGURE 15. Results showing effect of structural damping, wing density and air density.

The agreement is good, particularly near $\tan\psi=0$. The curve represents the method of solution suggested for investigations at high Mach number (Section 5).

6.2. EFFECT OF VARIATION OF THE RELEVANT PARAMETERS IN A TWO-DEGREE-OF-FREEDOM PROBLEM

A type of problem to which the simulator is particularly suited is the effect on flutter speed and frequency of the variation of a single coefficient or group of coefficients. To demonstrate this type of solution a real problem was taken, namely, flexure-torsion flutter for one of a series of flutter models being tested at high Mach number by the ground-launched rocket technique. Details of the model are given in Table I. The following parameters were varied:—flexural stiffness, torsional stiffness, flexural axis position, inertial axis position, radius of gyration, structural damping in each degree of freedom, wing density, air density and each of the twelve aerodynamic derivatives. The results are shown in Figs. 13-16. Theoretical calculations have not been made for comparison, because of the effort involved, but the general variations are in agreement with the general theoretical solutions.

These particular curves have proved most valuable in the investigations of any discrepancy between the experimental and theoretical results. For example, the aerodynamic coefficient $l_{\dot{\alpha}/dt}$ has little effect on the flutter speed, therefore it is unlikely that any discrepancy can be explained by supposing an effect of Mach number or aspect ratio on this derivative.

TABLE I

MODEL WING DETAILS

Wing span, root to tip	2 ft.
Wing chord, untapered	1 ft.
Wing thickness/chord	0·1
Wing section	R.A.E. 101
Flexural stiffness (measured at 0·7 span) l_δ	= 1,680 lb.ft./radian
Torsional stiffness (measured at 0·7 span) m_θ	= 680 lb.ft./radian
Distance of flexural axis aft of leading edge	= 0·3 ft.
Distance of inertial axis aft of leading edge	= 0·47 ft.
Radius of gyration about inertial axis	= 0·295 ft.
Wing mass/unit span	= 0·017 slugs/ft.

NOTE: De-coupled flexural and torsional modes were used in the calculations.

7. Conclusions

This simulator for flutter problems in two degrees of freedom was intended to demonstrate the possibilities of this type of machine and to act as a prototype for the six-degrees-of-freedom machine. It has been very useful both in illustrating the principles of electronic simulation and also, in indicating some modifications required to the original scheme. Since only readily available components were used, the overall accuracy was expected to be about one per cent. This accuracy has been achieved with well-conditioned problems. With ill-conditioned problems the accuracy is not so good but there is the advantage that the machine will indicate that the problem is ill-conditioned, and hence sensitive to small changes in the coefficients. Since the data on which the calculations are based are rarely accurate to one per cent., this indication is very valuable.

As a result of the satisfactory operation of this prototype, a machine to solve flutter problems in six degrees of freedom has now been built. It uses the same fundamental circuits, but the stability and selection of the components is, in general, to 0·1 per cent. In addition, high gain amplifiers are used and with these improvements the overall accuracy is maintained at one per cent., in spite of the greatly increased possibility of error.

Additional units have been developed to improve the recording of the results obtained from the simulator. These include a frequency meter, phase angle recorder, amplitude recorder, and a resonance unit, by means of which the response to a forced oscillation may be obtained.

ACKNOWLEDGMENT

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REFERENCE

SMITH, F. (1949). The Electronic Simulator for the Solution of Flutter and Vibration Problems. A.R.C. Current Paper No. 26, October 1949.

Training of Test Pilots

by

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(*Commander, Empire Test Pilots' School*)

1. Introduction

Never before in the history of aviation has the test pilot been so important as he is today. Now that military aircraft are travelling faster than the speed of sound and climbing to over 50,000 ft. in a matter of seconds, with powered controls, pressurised cabins, ejector seats, special oxygen equipment and such like being the order of the day, it is little wonder that the human being whose job it is to fly in these modern high-speed missiles requires more than ordinary Service flying experience if he is to take his place successfully in the team with today's technicians and designers. The day has long since passed when any good pilot could set himself up as a test pilot. The term "test pilot" covers a large field of work, testing aircraft and the complicated equipment fitted in the new revolutionary designs being produced.

An attempt will be made to cover this large field of test flying. The term "test pilot" could be applied to the pilot who tests any of the following:—

(*a*) the prototype
(*b*) research in aerodynamics
(*c*) engine development
(*d*) radio and electrical equipment
(*e*) bomb sights and armament
(*f*) automatic pilots, instruments, and so on
(*g*) aircraft off the production line,

as well as a host of other things.

The real test pilot is the pilot who tests the prototype or the pilot on aerodynamic research. These are the men who, in every respect, must possess real ability. Not only must they be unusually good pilots, but they must be broadly experienced with balanced judgment on a large variety of aircraft, and must possess the ability to talk, write and understand the technician's language, to enable them to fit into the modern test team. Of the many good pilots who are trained today, only a few have the attributes of a first-class test pilot. The field is large and varied, and there is space only to touch on the main subjects of the training of the test pilot.

2. Early Flying Days

Colonel Cody, the Wright Brothers and other early pioneers designed and built their own aircraft and then had to teach themselves to fly, at the same time endeavouring to test their own machines. This they did with a certain measure of success. All the more credit, then, to these fore-runners of aviation, but their problems were very different from those of today.

3. Between the Wars

After the First World War, and until the outbreak of the Second, any good pilot was selected for a test pilot's duties. After some years of test flying experience, either he settled down as a good test pilot or he continued as a good flyer but not a test pilot. Being self-taught these pilots had to learn the hard way and those who had not the skill, aptitude and intelligence to learn the tricks of the trade quickly, and to learn them from their own and others' mistakes, did not last long. The self-taught pilot in those days, if a bomber pilot, always criticised the aircraft he was testing for manoeuvrability, performance and control, from a bomber pilot's point of view; similarly, a fighter pilot turned test pilot would criticise every type he tested with an analogy to the handling qualities of the ideal fighter. Harmony and balance of control was something our aircraft badly lacked.

4. Beginning of the Second World War

Soon after the outbreak of the Second World War, aircraft developed by leaps and bounds. Greater speeds and higher altitudes were attained, as always in time of war when the nation's entire financial and scientific resources are mobilised. Fighting air crews were talking in comparatively new phrases such as "turning circle."

B.E.1. Certificate.

This is to certify that the aeroplane B.E.1. has been thoroughly tested by me, and the mean speed over a ¾ mile course with a live load of 25 stone and sufficient petrol for one hours' flight is 58-59 m.p.h.

The rate of rising loaded as above has been tested up to 600 ft. and found to be at the rate of 185 ft. per minute.

The machine has been inverted and suspended from the centre and the wings loaded to three times the normal loading.

On examination after this test the aeroplane showed no signs of defect.

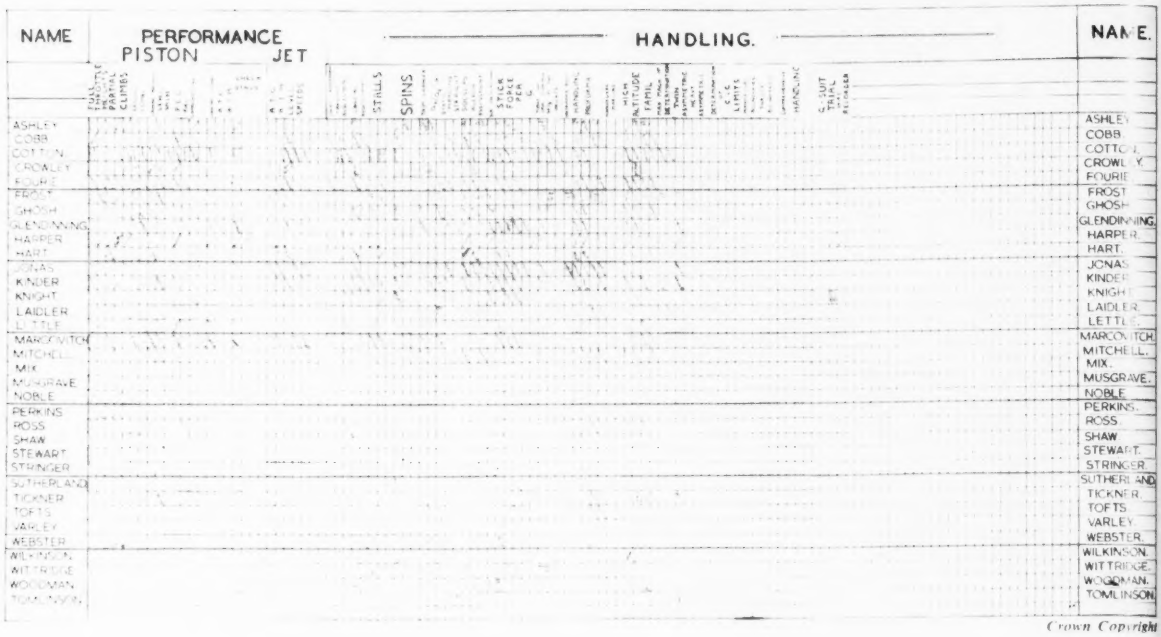
14th March, 1912, South Farnborough.

(Signed) S. Heckstall Smith, for Superintendent, Army Aircraft Factory

SKETCH No 10

FIGURE 1. An example of a test pilot's report in the early days of flying.

A Section Lecture given before the Society on 16th October 1952.



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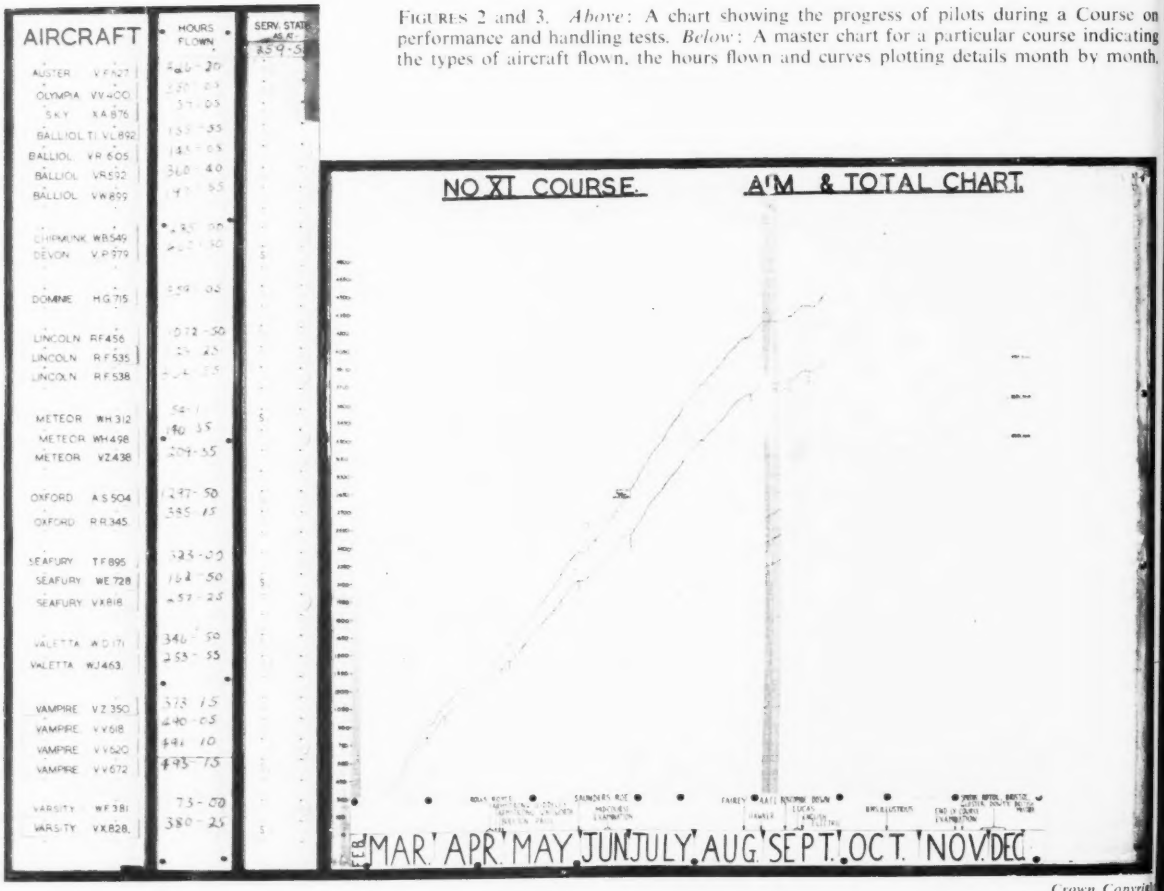

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FIGURES 2 and 3. *Above*: A chart showing the progress of pilots during a Course on performance and handling tests. *Below*: A master chart for a particular course indicating the types of aircraft flown, the hours flown and curves plotting details month by month.

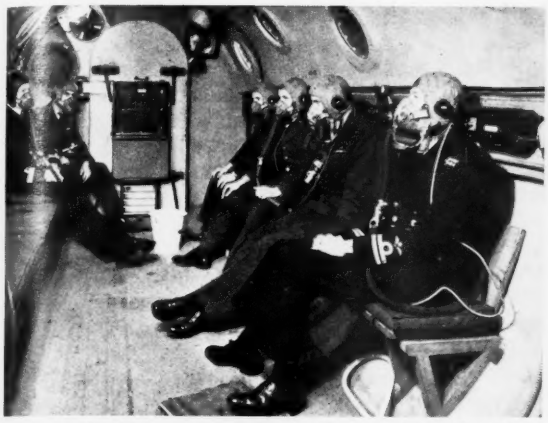

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FIGURE 4. Students undergoing tests in the high altitude chamber at the Institute of Aviation Medicine.

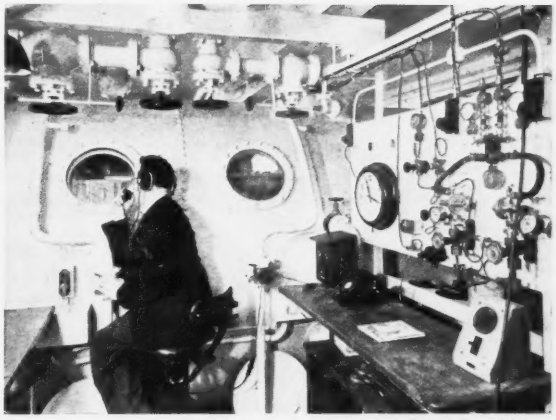

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FIGURE 5. The control room of the high altitude chamber at the Institute of Aviation Medicine.

"manoeuvrability," "stick forces," the effect of "g" and so on, to all of which little attention had been paid in the days of peace. There were new requirements in military aircraft of major importance in keeping a lead in the air war. Little wonder then that, experienced as many test pilots were, they could not fully appreciate these new requirements. How could they be up-to-date and appreciate the future trend of events if they lacked first-hand experience against enemy aircraft in combat?

Aircraft were becoming much more complicated in every sense. Heavier loads were being carried, engines were increasing in horsepower, wing loadings were higher than had ever been foreseen. Fighter pilots talked of the "g" they could sustain before blacking out in turning inside enemy fighters; bomber pilots talked about the manoeuvrability of their aircraft in evading flak areas and enemy fighters, or bombing from unsteady platforms, of the bomber's armament, as well as many other things. Times had changed, things were moving quickly. Many new ideas were necessary in future military aircraft, and the man with this vital store of knowledge, which designers needed, was the experienced fighting pilot.

5. A School for Test Pilots

Wisely, the Air Ministry appreciated the need for modern and specialised training of good war-experienced pilots to become test pilots. Pilots who could criticise design, armament and general layout in new machines. Pilots who could bring first-hand knowledge to design teams on the handling qualities of new aircraft. With their increasing complexity it was of vital importance to assist test establishments and the Industry by the influx of new blood. Pilots not only with a broad knowledge of combat experience but test pilots with a higher technical knowledge than ever before. Pilots who could speak the same language as technical design staffs. Pilots trained in aerodynamics and the theory of practical flight. Thus, a test pilots' school was established in 1943 at the R.A.F. Station, Boscombe Down, where it operated within the organisation of the Aeroplane and Armament Experimental Establishment. Its terms of reference, briefly, were to provide suitably trained pilots for test flying duties in aeronautical research and development establishments within the Service and Industry.

The inauguration of this School aroused widespread interest throughout our own Air Force and among our war-time allies, and those attending the earlier courses included many American, Dutch, French, Norwegian, Greek, Polish and Chinese nationals, besides Royal Air Force and Dominion representatives. The Aircraft Industry also supported the course, and some of the most eminent test pilots in the Industry today were among the first students. In July 1944 the School was renamed "The Empire Test Pilots' School."

6. The Empire Test Pilots' School

The School staff is headed by a Commandant of the rank of Group Captain, and under him are a specially selected flying tutorial staff on the one hand and a scientific and technical staff on the other.

On the flying side there is a Wing Commander, or, as at present, the post is filled by a Commander (E.), Royal Navy, who is known as the Chief Test Flying Instructor. He is assisted by three Squadron Leaders. The members of this team have all passed through the School and have completed three or more years of active test flying. It is their duty to lecture to the students on flight test routine, to correct the students' written flight reports and to give air instruction at the beginning of each new series of tests. They, in turn, are assisted by three flying instructors, as well as by flight engineers, signallers and navigators.

The civilian scientific side has a senior scientific officer who is known as the Chief Technical Instructor, and he is assisted by an experimental officer. Both these officers are highly qualified and have had considerable flight-testing experience. It is their duty to lecture and to direct the students in the academic side of flying. They cover a broad and highly technical field of knowledge. Both these officers are pilots and, as a special concession, the Ministry of Supply allow them to fly the School's aircraft. This, naturally, is of great assistance

to them in lecturing to the students, and enables them to talk with much more authority. These scientific officers have three technical assistants.

7. Location of the School

The School is fortunate in being situated at the Royal Aircraft Establishment at Farnborough as many of the R.A.E. technical and scientific personnel can be called upon to lecture.

Some of the aircraft firms are invited to help with technical and design staff lectures and the Aircraft Industry renders valuable service by allowing the course to visit the various works.

The School works a five-day week, and the course lasts nearly a year. Staff, aircraft and accommodation allow for a full course of 35 students. Each working day opens with a lecture either by the flying or by the technical tutorial staff. Lectures and technical report writing go hand in hand with the practical flying tests, and neither can exceed the other. There are 32 aircraft of 14 different types, ranging from light machines to heavy four-engined bombers. The servicing of them is the responsibility of the R.A.E. civilian engineers, who give excellent service.

The aim of the School is to select the cream of Service pilots each year from the various R.A.F. Commands and to give these pilots a varied and cross-sectional training on all types of aircraft. It is aimed to cover all those tests which students may expect to meet during their active test-flying careers. A typical course at the School is the present one, which numbers 33 students—6 Naval pilots, 4 Americans, 20 R.A.F., a Canadian, an Australian and an Indian. The course opens in February each year and passes out in December. In the Royal Air Force List, against each successful student's name is the symbol T.P. (Test Pilot). The top man of the course is awarded the McKenna Trophy, a memorial to Group Captain McKenna who was killed when acting as one of the early Commandants of the School.

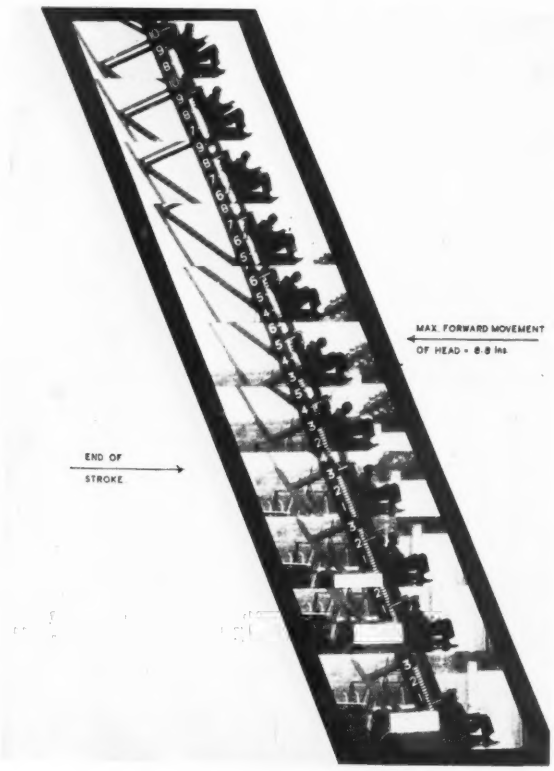

FIGURE 6. An ejector seat test rig.

8. Other Test Pilots' Schools

The only other test pilots' schools in existence are run by the Americans. The U.S. Navy has one which runs two six-monthly courses a year, and a lot of importance is attached to it. Their Commandant and some of the staff are graduates of the Empire Test Pilots' School. Their's is a 30-pilot course, and although they select their students carefully, they fail on an average about 20 per cent. of each course as unsuitable for test pilots' duties. It is understood that the U.S. Army also has a school.

9. Selection of Students

The selection of students is a meticulous and thorough business. The Air Ministry call each year for volunteers for the School from all the R.A.F. Commands. There are some 80 or more applicants, of whom only 16 or 18 will be required and they are selected as students to fill the vacancies on the Test Pilot Course. The confidential records are forwarded to the School for careful perusal, and it may be decided that only 25 to 30 of the 80 have the background and educational knowledge considered suitable. Some months before the course begins, these 25 to 30 candidates are invited for a three-day stay at the School. During this period the staff and candidates mix freely, the aim being to assess each candidate's suitability. The candidates are given a short lecture, an elementary examination to determine their educational standard and intelligence and a short test flight with the School's flying tutors. On the third and last day, an Air Vice-Marshal heads the Selection Board at which the final choice is made. All candidates then return to their units, and the successful ones are posted to the course several months later, in the new year.

The modern jet pilot does not build up thousands of hours, as pilots on propeller aircraft have done. It would be preferable to select students at the age of 25 to 26, but today's young pilot at that age barely has 500 flying hours to his credit. Until now pilots have been selected for training up to 32 years of age, and on the most recent course the average age was 28. If younger pilots are selected they can be given a broad training on all types of aircraft before they have settled down with fixed ideas on any one type and have become biased in their flying outlook. It stands to reason that by training younger pilots the Service will get at least two, and in some cases three, tours of test flying duties once they have completed the course. The older type of pilot, who

had to be accepted in the past, having spent a year under instruction followed by three years' test flying, was too old to return for a second tour of test flying duties. The ideal selection would be a balance of pilots drawn from Fighter, Coastal and Bomber Commands, and this is done as far as possible.

Test pilots' duties call for the highest medical grade possible in flying crews, and there have been rare instances of pilots beginning the course, and in some cases completing the course, only to find that they were unable to stand up to the heavier strain of test-flying duties. This sort of wastage is expensive, and in 1951 the medical authorities were asked to institute a very careful grading of all candidates' medical records before they came for interview. Although this careful grading takes place before the course, all students must pass a further medical test by the Station Doctor on joining.

Further medical tests are made on all students in the high altitude chamber at the Institute of Aviation Medicine at Farnborough. Here the students are taken to 40,000 ft. or more where they remain under medical supervision and their reactions are checked.

A test pilot who fails in the air can cost the country a lot of money, particularly if he is flying a prototype. This may delay progress considerably. Aircraft today, unlike pre-war days when each machine cost a few thousand pounds, may now cost a million pounds apiece. It is essential therefore that only the best pilots in every way be trained on this expensive test pilots' course, which is 41 weeks of intensive study and flying.

The 30 students are divided into syndicates A, B, C and D, each under a flying tutor. During the course the students change syndicates several times and the year's work is by no means easy. While the elementary and academic side of aviation is taken hand in hand with practical flying tests and report writing, the aim is certainly not to turn these young pilots into scientists. A good pilot with common sense should always complete the course, but an average pilot, however good he is academically, cannot be tolerated. The value of aircraft today and the importance of directing design teams along the right lines only warrants the very best pilots being trained. When the students have completed the course, the R.A.F. and R.N. pilots are posted to the Establishments at Boscombe Down, Farnborough or Felixstowe for test flying duties. Like the Staff College Graduate, the student, on completing the course, has only really had a grounding in test-flying technique. He will only develop into a test pilot after practical experience in test flying and his use as a test pilot will not be very great until he has completed at least a year and gained practical test-flying experience at one of the Establishments.

Each year more and more intricate technical and scientific equipment goes into the design and manufacture of the modern machines and this is placing an ever-increasing burden upon the limited faculties of the human pilot. The test pilot now has so many things to cope with that it is almost impossible for him to record, in a limited time, everything that is happening around him. Therefore, machines such as the automatic

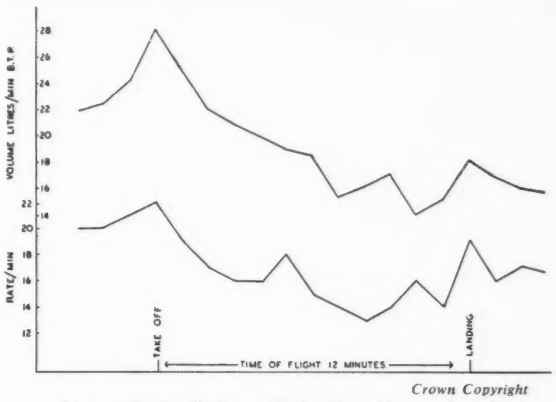

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FIGURE 7. A pilot's respiration in a Meteor aircraft.

recorder and the wire recorder are carried on many test flights today.

The automatic recorder takes a series of photographs of the instrument readings as the machine is in flight. The wire recorder is a machine into which the pilot dictates the performance of his aircraft. After the flight, this wire is played back slowly and a record of the report is taken down.

The respiratory actions of pilots have been recorded during normal take-offs and landings. This sort of test is fascinating because every pilot seems to have a different psychological approach to flying, and this approach is appreciably altered by emotional factors caused by the strain of flying. This again varies with his like or dislike of various aircraft. It is the author's belief that this psychological factor can cause a loss of up to 30 per cent. of his normal faculties when flying.

Assessing students at the end of each course requires considerable study of the individual's make up, and the staff pay particular attention to the honesty and integrity of report writing.

With the revolutionary design of today, it is essential to train, and train thoroughly, pilots for test-flying duties. Only the very best can be trained as test pilots, otherwise designers and technicians may be led astray.

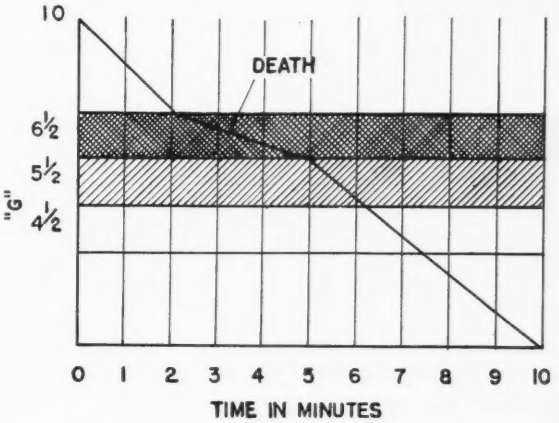

FIGURE 8. Empire Test Pilots' School. Effect of gravity on a normal pilot in flight.

There is still much to be done on fatigue study of air crew. For example, heavy controls, noisy aircraft, poor cockpit layout, are all factors which increase fatigue. The Institute of Aviation Medicine at the R.A.E. are doing excellent work in studying these problems with their own medical team of test pilots.

Conclusion

Progress in design and development is probably faster than ever before, and it might well be that there is only a limited number of years in which test pilots in any quantity will be needed. Perhaps in a few years, high-speed directed missiles travelling at nearly 2,000 m.p.h. will take the place of interceptor fighters? Even the bomber pilot may eventually be replaced by some form of directed robot which will enable the bomber to fly at fantastic altitudes, and the heavy and intricate devices now necessary for the safety and welfare of air crews will be eliminated.

The qualities of a good test pilot are patience, exceptional flying ability, willingness to take risks when demanded, sincerity, honesty, breadth of experience of a multitude of types and the ability to speak, write and understand the designers' and scientists' language. The test pilot who has all these qualities has probably yet to be born.

TECHNICAL NOTES

The increasing flood of technical information makes it difficult to publish even abstracts of such information and it has become still more difficult to publish technical items of information which do not reach the status of full-length papers.

Under this general heading of TECHNICAL NOTES it is hoped that members of the Society, and indeed all those who read THE JOURNAL, *will help in contributing just those very items of useful information which normally might not see the light of the printed page.*

There will be no set form for these Notes. They may be illustrated or not. They can be short papers of a thousand or two thousand words; or abstracts and comments upon unpublished papers or upon published papers with a limited circulation; or notes of some interim results of research in hand and notes for further research; or in the form of a letter raising technical points or asking technical questions; or letters commenting on Notes already published.

These pages are intended to be a technical forum where members can argue and discuss; where they can inform and be informed; and pass on their own experience, or air their technical difficulties. Contributions will be eligible for THE JOURNAL *Premium Awards and they will be published as soon as possible after they are received.*

No member need ever say that his particular subject does not get discussed in the pages of THE JOURNAL. *He can always raise it himself, for these pages are his pages.*

Of the Notes published in this issue we welcome particularly that by Dickinson and Hadley. For some years the Society has published authoritative Data Sheets on Aerodynamics, on Structures, on Performance and on Fuels and Oils. Much of the information and the accuracy of these sheets have been due to tests which have been made by firms. The present Note gives some interesting results of a method adopted by Armstrong-Whitworth to obtain information for the Society's Structures Committee. Technical notes on the Data Sheets are particularly welcome.—THE EDITOR.

Tube of Least Weight for Given Torsional Stiffness

by

H. B. HOWARD, B.A., F.R.Ae.S.

(*Ministry of Supply*)

CONSIDER a thin-walled tube fixed at one end and subject to torque of known distribution. The problem is to find how the thickness of the wall should vary along the length so that the weight is a minimum for a given angle of twist at the free end.

At distance x from the fixed end, let T be the applied torque, A the enclosed area of the tube, P its perimeter and y the wall thickness. In the first instance y is taken as constant around the perimeter. It is assumed that the tube obeys Batho's relation for torsional stiffness so that the twist θ at the free end is given by

$$\theta = \frac{1}{4N}\int_0^L \frac{TP}{A^2 y}\,dx, \qquad . \quad . \quad . \quad (1)$$

L being the length of the tube and N the shear modulus.

The weight of the tube is

$$W = \rho \int_0^L Py\,dx. \qquad . \quad . \quad . \quad . \quad (2)$$

T, P and A are taken as known functions of x. The problem is to find the form of the function y which makes the integral in (2) a minimum while keeping the integral in (1) constant.

From the calculus of variations, if F and G are both functions of x, y and $p\,(=dy/dx)$ then the condition that $\int_a^b F\,dx$ is a minimum while $\int_a^b G\,dx$ is kept constant, is given by the Euler equation

$$\frac{\partial F}{\partial y} - \lambda\frac{\partial G}{\partial y} - \frac{d}{dx}\left(\frac{\partial F}{\partial p}\right) + \lambda\frac{d}{dx}\left(\frac{\partial G}{\partial p}\right) = 0, \qquad (3)$$

x, y and p being treated as independent variables when performing the partial differentations. λ is a constant depending on the particular conditions.

In the present problem $F = Py$ and $G = TP/(A^2 y)$. Neither contains p so that $\partial F/\partial p$ and $\partial G/\partial p$ vanish, and (3) becomes

$$P + \lambda\frac{TP}{A^2 y^2} = 0. \qquad . \quad . \quad . \quad . \quad (4)$$

From which it follows that

$$y^2 \text{ varies as } T/A^2,$$
$$y \quad \text{,,} \quad \text{,,} \quad \sqrt{T}/A.$$

For least weight the thickness of the tube should vary along the length, directly as the square root of the torque and inversely as the enclosed area.

The same arguments apply to the necessary increase in thickness of a given tube to provide a given increase in torsional stiffness. Let t (a function of x) be the original thickness and y the increase. Then we can write $t+y$ for y and obtain

$$t + y \text{ varies as } \sqrt{T}/A.$$

The increased thickness should be so distributed as to make the final thickness obey the optimum law.

No assumption is made about the shape of the tube, which can vary continuously in any manner provided that the Batho relation can be taken as holding.

Received August 1952

If the thickness is not constant around the perimeter the law will still hold provided that its distribution around the perimeter is constant. Considering any section, let y be the mean thickness and t the thickness at a point, then the law holds if P/y is a constant multiple of $\int \frac{dP}{t}$ around the perimeter. For example, it would apply to a box beam with flanges and webs of different thicknesses provided that the ratio of flange thickness to web thickness and the ratio of flange length to web length were both constant along the tube.

The case of most practical interest is the stiffness of a tapered tube under a concentrated torque at the free end. A box beam in a wing and a rear fuselage body are examples. For a constant torque the optimum condition is the same as the constant shear stress condition (for which $y \propto T/A$). This suggests a practical procedure for stiffening such a tube in the most economical manner. The shear stress should be calculated at points along the tube under unit torque at the free end and material should be added where the shear stress is greatest. This will give a guide to the best compromise between the conflicting demands of uniform bending strength and optimum torsional stiffness.

The author acknowledges the permission of the Chief Scientist, Ministry of Supply, to publish this Note.

Pressure Tests on Flat Aluminium Alloy Panels

by

C. J. DICKINSON and H. R. HADLEY

(Sir W. G. Armstrong Whitworth Aircraft Ltd.)

THIS NOTE describes brief tests made to check a proposed extension to the Royal Aeronautical Society Stressed Skin Data Sheets on stresses and deflections in flat panels subjected to normal pressure. Simple modifications to the test rig, which greatly improved the edge fixing, are also included.

INTRODUCTION

The Royal Aeronautical Society Stressed Skin Data Sheet 02.09.02 provides information on the deflections and stresses in a flat panel with fixed edges when subjected to a normal pressure. The stresses and deflections, expressed in the form of non-dimensional parameters $(f/E)\,(b/t)^2$ and δ/t are plotted against the normal pressure which is expressed as $(p/E)\,(b/t)^4$ where

- f stress (lb./in.^{2})
- E Young's modulus of the plate material (lb./in.^{2})
- b length of short side of plate (in.)
- t thickness of plate (in.)
- p normal pressure (lb./in.^{2}).

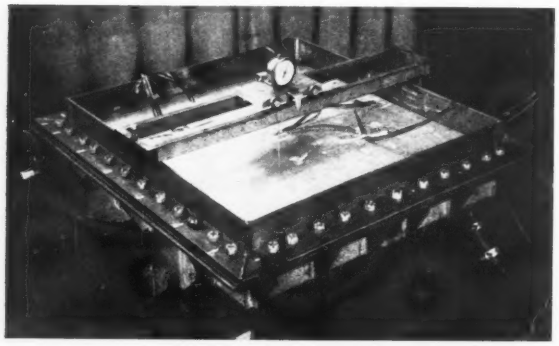

FIGURE 1. Pressure test rig.

Received December 1952

At the present time the maximum value of the parameter $(p/E)\,(b/t)^4$ is 500, which rather limits the usefulness of the information, and a draft data sheet extending this value to 3,000 has therefore been prepared. This Note describes brief tests made to check the extension.

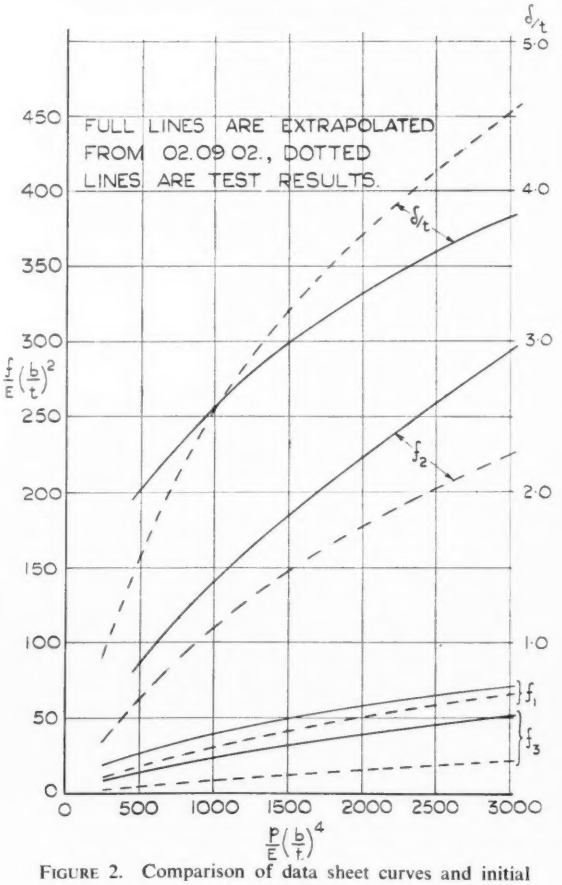

FIGURE 2. Comparison of data sheet curves and initial test results.

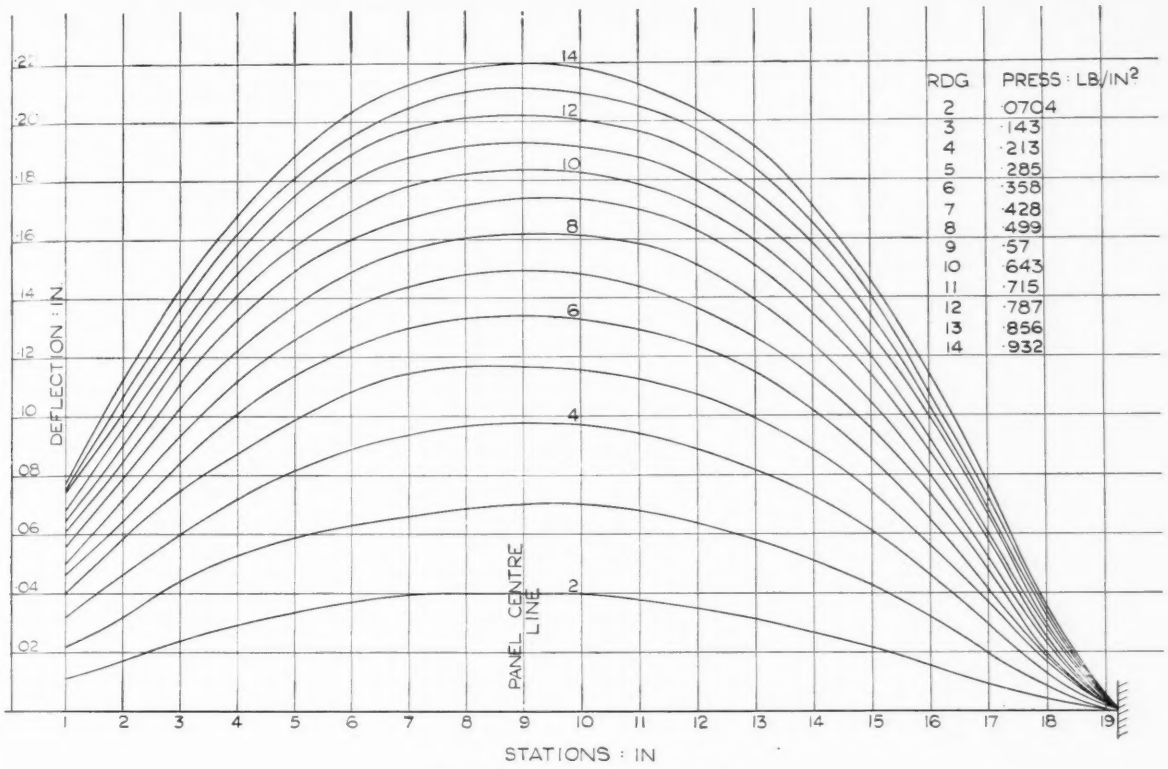

FIGURE 3. Deflected form of panel.

LOADING RIG AND INITIAL TEST

The pressure panel, a sheet of 18 S.W.G. light alloy to D.T.D. 390 specification, was clamped by a steel angle frame over a substantial mild steel box (which had been used for other pressure tests) and formed a test panel, 20½ in. square (Fig. 1).

Standard ⅜ in. diameter bolts fitted in reamed holes were used to clamp the angle frame to the pressure box, "Bostik" sealing compound being used to obtain pressure tightness.

Electrical resistance strain gauges were used to measure the strain of both faces of the test panel at its centre and also at the middle of one edge, each measuring point being duplicated. The deflected form of the panel was also measured by a trolley gauge mounted as shown in Fig. 1 and, as it was not possible to obtain a full traverse, the gauge was positioned to give coverage to the edge where the strain gauges were fitted, thus omitting two inches at the opposite side.

The pressure in the test tank was controlled by a pressure reducing valve used in conjunction with a pressure bag loaded by hand or by dead weights. A water manometer measured the pressure, increments of two inches of water being applied up to a maximum of about 0·9 lb./in.², which corresponds to a value of 3,000 for the parameter $(p/E)\,(b/t)^4$. Strain gauge and trolley gauge readings were taken at each increment.

The stresses corresponding to the measured strains were calculated from the mean of the two sets of strain gauges, using the strain gauge factor for the gauge batch and assuming a nominal value of 10×10^6 lb./in.² for Young's modulus. The stresses at the centre of the panel were corrected for the double stress field, using a value of 0·33 for Poisson's ratio, while those at the edges were corrected for the appreciable distance of the gauge centre from the clamped edge of the panel.

The stress and deflection parameters, *i.e.* maximum tension stresses, f_1 at the centre of the panel and f_2 at the edge, the membrane tension stress f_3 and the maximum deflection of the plate, are plotted in Fig. 2 and

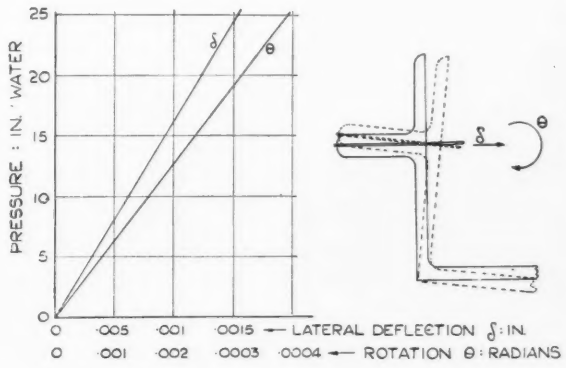

FIGURE 4. Distortion at middle of edge member. (One side only—opposite edge similar.)

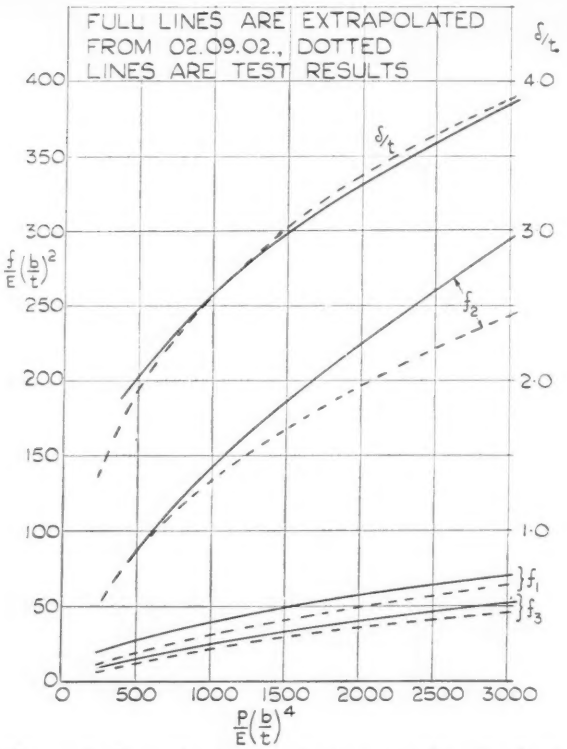

FIGURE 6. Comparison of data sheet curves and results of test with improved edge fixing.

compared with theoretical curves from the extrapolated data sheets. The deflected form of the panel at each pressure increment is also shown in Fig. 3 (the shape at zero pressure was unfortunately not recorded). The low membrane stress and high deflections suggest that the edge fixity is not adequate, and this was therefore checked by a brief test in which the distortion of the top edge clamping member was measured by dial gauges. The deflections which occurred, shown diagrammatically in Fig. 4, were small, but sufficient to relieve the membrane stress quite considerably.

ALTERATIONS TO THE RIG AND A FURTHER TEST

It was felt that the edge fixing could easily be improved and a stiffened flat steel plate ($\frac{1}{4}$ in. thick) was fitted between the test panel and pressure box, the edges being further reinforced by dowels fitted between the clamping bolts. A spacing shim was also fitted between the stiffened plate and test panel, and holes provided in the former for strain gauge leads, and air pressure (Fig. 5).

A further test gave the results shown in Fig. 6.

The deflection expressed at δ/t, is derived from the deflection at the centre of the panel relative to the panel form at zero pressure, and shows good agreement with the theoretical curves. The stress parameters for f_1 and f_3 show a better agreement than in the first test, but there is still some divergence in the case of the edge stress function. The deflected form of the panel at each increment of pressure is also shown in Fig. 7.

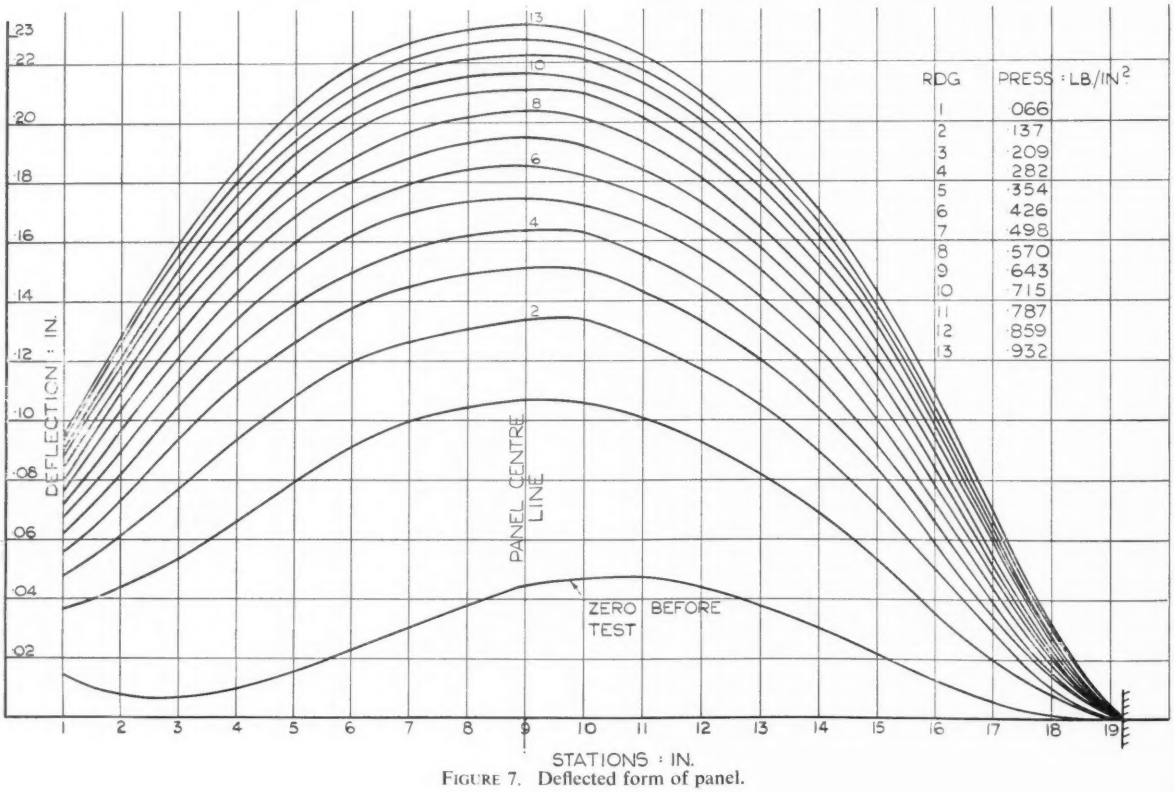

FIGURE 7. Deflected form of panel.

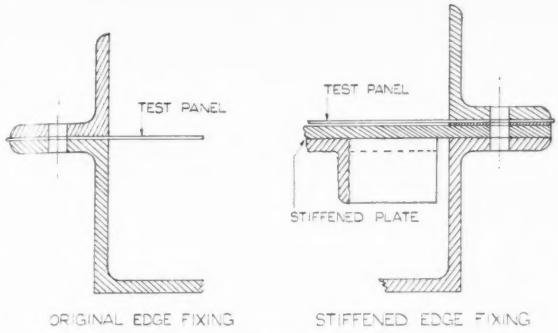

FIGURE 5. Comparison of edge fixing.

CONCLUSION

In general, the test results with the improved edge fixing show a fair agreement with the extrapolated data sheet curves, the stress being about 80 to 95 per cent. of the expected values. This underestimate may well be due to the value of Young's modulus adopted, but this point has not been checked.

The deflection parameter δ/t has shown good agreement with data sheet curves when estimated from the shape at zero pressure, even when there is some "oil-canning" present (as shown by another test not reported herein).

A Method of Measuring Post-Yield Strain

by

F. J. WOODCOCK, A.M.I.E.E., A.F.R.Ae.S., and K. R. WEISS, Dipl.Ing.

(*Royal Aircraft Establishment and Fighting Vehicles Research and Development Establishment*)

INCREASING interest has been shown recently in the measurement and interpretation of post-yield strains. Early investigators determined the nature and magnitude of such strains by observing the distortion of a grid of fine lines inscribed on the unstrained metal. A development of this method involved the use of a photographically deposited grid.

In the present instance the initial requirement (August 1948) was for the measurement against time of strains of the order of 4 per cent. occurring as "fast transients."

As the wire resistance strain gauge element was well established, it was natural to consider its extension to post-yield measurements, and it later became apparent that this had already been done by Swainger[1].

1. THE ELEMENT MATERIAL

A suitable element must be capable of withstanding the required high value of strain plus a reasonable safety margin, and should possess a strain sensitivity or gauge factor $S=(\Delta R/R)/(\Delta L/L)$ which is, as far as possible, independent of strain.

At the Royal Aircraft Establishment, investigations into the behaviour of fine wires under strain had shown that for many materials the sensitivity changed during the first one per cent. strain. This disadvantage was accentuated by the fact that for any subsequent decrease in strain the sensitivity reverted to its initial value.

Fortunately, annealed copper and a 60 per cent. cupro-nickel alloy were both found to be exceptions to this general rule. Although there is little difference between the strain sensitivities of these materials, the resistivity of the alloy (47 to 50 microhm. cm.), is approximately thirty times that of copper. Thus, other things being equal, the alloy would undergo a greater resistance change, which is more easily utilised. In addition, with a copper element, the resistance of connecting leads would cause a considerable reduction in the virtual strain sensitivity. This effect is considered later. The temperature coefficient of resistance is also very much in favour of the alloy. In the range 0-100° the figure for the alloy is about 0·00002/°C., while that for copper is 0·0043/°C.

Originally received May 1952; revised version November 1952

2. THE GAUGE ELEMENT

Having selected a material, it was necessary to decide what form the gauge element should take. Checks on commercial wire resistance elements proved them to be incapable of standing the high strains, even when made with a 60 per cent. cupro-nickel alloy. As the failure always occurred at the junction of the lead wire with the strain-sensitive wire, some elements were tested with these joints in an unstrained condition. These failed at strains varying between 3 and 10 per cent. This method of using commercial elements was considered unsatisfactory, however, as the process of unsticking the joints, to render them strain-free, was tedious.

The type of gauge element finally adopted consisted solely of a two-inch length of 44 S.W.G. (0·0032 in. diameter) double cotton-covered Eureka wire. The cotton covering was left in position, partly as a measure of insulation but mainly to ensure that the wire was engulfed with adhesive. It was thought that this would facilitate the transmission of the strain to the wire element. The usual paper base was omitted as it appeared that it would be more of an encumbrance than an aid. The nominal composition of Eureka is 56 per cent. copper, 44 per cent. nickel. This departure from the 60/40 ratio did not appreciably affect the form of the characteristic.

3. TEST RESULTS

The results of the comparison tests are summarised in Table I. Durofix adhesive was used throughout and generally was allowed to dry for about two days. The gauge factor quoted is the measured value, *i.e.* it takes no account of the resistance of the connecting leads.

The mechanical and electrical properties of resistance wires depend upon details of fabrication and heat treatment. Such details were not available for the materials considered here, although it is understood that cotton-covered Eureka wire is normally supplied in an annealed condition and it is believed that the Minalpha and Ferry wires were in a similar condition.

Tests 1 to 8 on commercial gauge elements were undertaken with the joints between the strain sensitive elements and the lead-in wires deliberately raised to render them strain-free. The breaking strains of 3·2 per cent. and 3·5 per cent. for the British gauges fabricated from Advance wire (Tests 7 and 8) may seem surprisingly low for such a wire, but they were due to fractures occurring in the paper base. Such fractures cause excessive local strain in the wire, resulting finally in a complete break.

The breaking strains of Tests 9 and 10 were exceptionally low for the same reason. The use of a more homogeneous paper base gave the improved result of Test 11 and several exactly similar "secondary" elements, which were mounted on the tensometer test piece but not monitored continuously during test, showed breaking strains in excess of 8 per cent. (Test results associated with secondary units are not included in the table.) Similarly, secondary elements associated with Tests 12 and 13 withstood strains of about 8 per cent., the final break being due to fracturing of the paper.

Tests 14-17 were with cotton-covered Eureka wire, a paper base being used for Tests 14 and 15 only.

Tests 14 and 15 had to be abandoned when the tensometer test piece failed at 9 per cent., but in neither instance had the gauge element broken. Test 14 had no secondary units associated with it while Test 15 had five, one of which failed at some strain below 9 per cent. This break was also due to fracturing of the paper.

Test 16 involved one continuously monitored element together with two secondary elements fixed with adhesive which had been allowed to dry for about three days (a little longer than usual), and six secondary elements which had been dried for six days. Failure at 15 per cent. of all three of the first batch was due to the adhesive peeling off. All six elements of the second batch had neither broken nor peeled off, even at 16 per cent. strain. Test 17 involved one monitored element and twelve secondary elements. All elements withstood 7 per cent. strain satisfactorily but the test was abandoned when it was noted that several secondary units were peeling off at 9 per cent. strain. The low gauge factor quoted for this test was due to long unstrained ends that were left on the element.

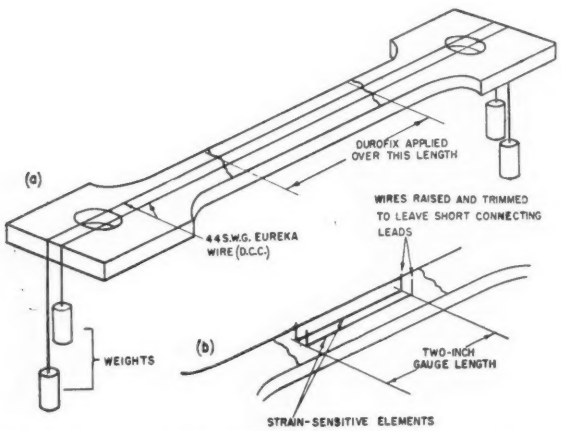

FIGURE 1. Method of fixing wires on to tensometer test pieces.

TABLE I

RESULTS OF TESTS ON VARIOUS GAUGE ELEMENTS

Test No.	Type of element	Wire material and diameter:	Nominal initial resistance: ohms	Resistance increase at break: per cent.	Breaking strain: per cent.	Initial gauge factor
1	American Commercial Gauge	Advance 0·0012	120	8	4·8	1·7
2				11·4	6·9	2·1
3				10·0	5·2	1·7
4				19·2	10·2	1·7
5				10·0	4·8	1·7
6				15·9	9·5	1·7
7	British Commercial Gauge	Advance	100	3·0	3·2	1·7
8				3·0	3·5	1·3
9	Single Wire On Paper Base	Minalpha —Fully Annealed 0·001	86	0·19	0·4	—
10			91	—	0·7	—
11			68	8·1	5·7	1·4
12		Ferry—Oxidised 0·002	100	5·0	8·0	0·6
13			44	15·0	10·0	1·5
14		Eureka—Double Cotton-Covered 0·0032	6·0	>11·0	>9·0	1·2
15			6·0	>11·0	>9·0	1·2
16	No Base		6·0	>18·0	>15·0	1·2
17			9·0	>6·3	>8·0	0·76

NOTES 1. Tests 9 and 10 used thin typing paper for a base. Tests 11, 12, 13, 14 and 15 used cigarette papers.
2. Ferry, Eureka and Advance are trade names for 55-60 per cent. cupro-nickel alloys.
3. Minalpha is a trade name for a material consisting of 85 per cent. copper, 12 per cent. manganese and 3 per cent. nickel.

Unless the wire is maltreated there is no reason for it to fail in tension. Minimum percentage elongation figures for various diameters of annealed Eureka wire are stated by the manufacturers to be:—

Diameters below 0·002 in.	5 per cent.
Diameters between 0·002 and 0·0024 in.	7 per cent.
Diameters between 0·0024 and 0·0076 in.	10 per cent.

These figures give the minimum elongation that may be expected; 60 per cent. cupro-nickel alloys are sometimes capable of elongations of up to 50 per cent.

4. APPLICATION OF GAUGE ELEMENT AND TESTING PROCEDURE

As a preliminary check, tests were made as follows. Some standard tensometer test pieces were cleaned with acetone and a number of lengths of Eureka wire were placed in position (*see* Fig. 1(*a*)). The wires were brushed with acetone, allowed to dry, covered with high quality

Durofix for a length of three inches and left for two to three days. Then with acetone as a solvent, the wires were raised, except for a central two-inch length, and trimmed to leave short connecting leads as shown in Fig. 1(*b*). Each of these test pieces was loaded several times to just within its elastic limit as a superficial check on the adhesive. They were then loaded until failure, the strains being measured over the two-inch gauge length with an optical extensometer and the resistance changes by a standard Wheatstone's bridge. The failure was usually due to the adhesive peeling off the test specimen, which invariably did not occur until the strain was more than 8 per cent.

For measuring the fast transients, a similar procedure was adopted for fixing the elements and for making a superficial check on the adhesive. Also, whenever possible, a strain-sensitivity curve was obtained before the actual measurement to provide an individual sensitivity figure for each element.

5. SIGNIFICANT CHARACTERISTICS

Special mention should be made of two significant characteristics of this method of measurement.

The first concerns the strain sensitivity. The individual sensitivity figures, to which reference has just been made, were invariably less than the nominal value of 2·1 for 60 per cent. cupro-nickel, and the reason for this is interesting.

The resistance of the two-inch strain-sensitive length of 44 S.W.G. Eureka is about 4·8 ohms. Thus, assuming a strain sensitivity for the wire of 2·1, a 5 per cent. strain produces 0·5 ohm change in resistance. The total resistance of the wire is, however, the 4·8 ohms of the two-inch strain sensitive length plus, say, 2·4 ohms for the two short unstrained ends. Thus effectively there is a change in resistance of approximately 7 per cent., and hence the virtual strain sensitivity $= 7/5 = 1{\cdot}4$. Provided that a substantial gauge of wire is used, copper connecting leads need cause no trouble, but the unstrained ends of the Eureka wire are seen to produce an appreciable effect. Thus the virtual value of the strain sensitivity is given by

$$S_E = \frac{Sl_1}{l_2}$$

where S_E = virtual strain sensitivity
S = nominal strain sensitivity
l_1 = strained length of wire
l_2 = total length of wire.

If only quarter-inch unstrained ends are left on a two-inch gauge length the sensitivity is reduced by 20 per cent. This may be important. On occasions when it is not possible to determine the virtual sensitivity by an initial calibration, it is thus necessary to know l_1 and l_2 accurately.

The second characteristic is concerned with the associated circuit. The simplest way of ensuring that the resistance change in the Eureka element results in a corresponding voltage change, is to connect it in series with a swamping resistance, as shown in Fig. 2. When investigating dynamic strains the steady component of the voltage across the element may be eliminated by using a blocking condenser. For steady and slowly varying strains two more resistors, R' and r', may be added to complete the bridge network. In either case large percentage changes in R result in an appreciably non-linear relationship between the resistance change ΔR and the corresponding change in voltage output Δv_o.

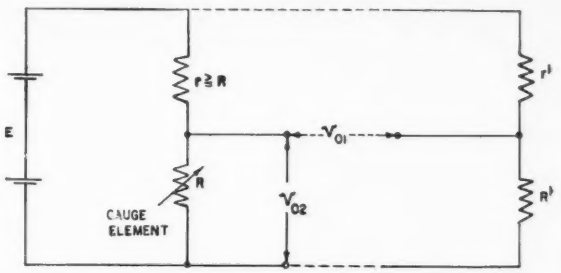

FIGURE 2. Associated circuits.

It can be shown that the relationship is, assuming a high impedance voltmeter,

$$\frac{\Delta R}{R} = \frac{\Delta v_o (R+r)^2}{R[rE - \Delta v_o (R+r)]}$$

When evaluating elastic strains, the denominator term $\Delta v_o (R+r)$ is usually neglected as $\Delta v_o (R+r) \ll rE$, but, for large post-yield strains, the evaluation must often include this term.

Clearly the linearity may be improved and record analysis eased by increasing the supply voltage E. If there is any tendency for this to over-load the element, increases in E must be accompanied by increases in r.

Attention has been confined to a voltage output. Similar considerations would apply to a current output.

ACKNOWLEDGMENTS

This work formed part of a research project directed by Mr. Uffelmann. Thanks are due to him, and Miss K. R. Maslen for information concerning the various forms of strain-sensitivity curves. This information is now recorded in Refs. 2 and 3. References 4 and 5 are concerned with more recent investigations but are included for completeness.

The authors acknowledge the permission of the Chief Scientist, Ministry of Supply, to publish this note.

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CORRESPONDENCE

The Journal

H. G. Wells in *The Work, Wealth and Happiness of Mankind* wrote:—

"In England we have come to rely upon a comfortable time-lag of fifty years or a century intervening between the perception that something ought to be done and a serious attempt to do it."

It is fifty-six years ago since the JOURNAL was founded as a quarterly publication, replacing the erratic publication, which had begun in 1867, of the famous Annual Reports.

The "comfortable time-lag of fifty years" has been handsomely exceeded, and something should now be said about the JOURNAL and its contributors and how it reflects the changing outlooks and activities of the Society itself.

What better occasion can be chosen than when the JOURNAL puts on a new dress? Men and women look better if they are well dressed, and feel better in a new dress. Yet all close observers of the human form divine would hesitate to judge that form on the dress it chose to hide it; and all editors are acutely aware that the chief page of any publication is the *CONTENTS* page.

No aeronautical publication with so much to say about itself as the JOURNAL of the Society, has said so little of itself. No other aeronautical technical publication can boast such a long and such a distinguished record.

In February 1920, C. G. Grey, an authority on these and many other matters to do with publicity, wrote (not in the JOURNAL!):—

"It is the custom of learned societies in this country to hide their lights under voluminous bushels, if not actually to hide their heads in the sand. . . . Though the Royal Aeronautical Society is the oldest of its kind, it is composed almost entirely of young men, as is natural, considering that, though the science of the air itself is old, the science of aeroplane and airship construction has come into being within the past nine or ten years, and the vast majority of those who have developed the purely scientific side have only been concerned with it for five or six years. Consequently the papers read at the meetings of the Royal Aeronautical Society and the subsequent debates, are such as to interest all engineers and those interested in engineering problems, for they have not reached the dry-as-dust stage which devastates similar meetings of old societies. The fact that the entertaining nature of these meetings is not better known is regrettable. . . . It is hoped that in future the Society's activities may become better known to that section of the community at large which has intelligence and uses it."

I cannot forbear quoting a little more from Grey's article on the Society at that time, for he noted a number of lectures which were to be given in the near future, among them one by Lord Montagu of Beaulieu on "A comparison of the cost of Transport and ton-miles by Land, Sea and Air."

Grey commented, "This should interest anybody concerned with any form of transport. For example, one might expect the audience to include . . . such notable persons as Messrs. Carter and Paterson (with or without the Co.) and Mr. Pickford, if they are still with us in the flesh."

Even the great C.G. would now find it a little difficult to name "notable persons," in the sense he used the words thirty odd years ago, in land and sea transport. At the meeting all the transport chiefs kept clear of any discussion. They did not fear the air, then, and now it is too late for them to find out which way the wind blows, for B.O.A.C. and B.E.A. know, and why should they let their obsolescent rivals have a breath of it?

I think the Society's meetings were more of an "entertaining nature" in those days than they are now, except for the Section lectures which, alas, are not usually reported in the JOURNAL, more's the greater pity. The bushels have multiplied in number and size and are now called Security Measures.

Grey himself, but ten years after the commendation I have quoted, was saying of the Society, not without rhyme and reason, that it was a mutual admiration Society. It has periodic heart beats that way. The metronome is always kept in readiness in the Lecture Halls of Aviation.

Nothing is better for the Society and for its publications than criticism, yet how often is that criticism too little and too late by the too ignorant. Members seldom offer any constructive comments to the editor of the JOURNAL, despite all their grumbles to one another that the JOURNAL is not what it was. I can assure them from long experience that it never will be, but there is always hope if enough members help.

Listen to the great Professor Bryan writing to the Secretary of the Society on June 4 1909.

"I consider that a great many of the theoretical papers published in the JOURNAL are rubbish and if others have any value that value is often hidden by mis-statements of well-known elementary principles of mechanics. . . . My criticisms apply exclusively to papers of a theoretical character. The descriptions of current experiments, airship, exhibitions and practical matters are safe ground about the value of which there can be no doubt . . . the plan should be discontinued of printing the speeches and votes of thanks and the accounts should only contain statements of the papers read. Remarks on papers should not be printed unless they are of real value and then should be based on written statements communicated by the speakers. Mathematical papers should not be printed in two columns, otherwise the formulæ are very difficult to decipher . . . and authors of papers who are practical men rather than mathematicians or physicists should be required to confine their papers to statements of experiments and not to air their views which are unfounded on substantial evidence."

Editors of papers, technical or otherwise, welcome letters from their readers, whether in damnation or praise, and the members of any Society owe a special and peculiar duty in this respect. The prestige, importance and value of a Society depend so much upon its publications which reflect in turn upon every member. No member can escape his responsibility by doing nothing when he feels something should be done. If he fails to say what kind of Journal he wants then he cannot grumble about the Journal he gets. Nor is it the slightest use putting up suggestions secondhand. The direct approach is the correct approach to save misunderstandings. Changes worth while are always considered with great care by the Journal Committee and the Editor.

I mentioned Professor G. H. Bryan. He was one of the leading mathematicians of his time, specialising in

applied mathematics, and undergoing part of his training under the great J. J. Thomson. He was awarded the Gold medal of the Society for his mathematical work on the theory of aeroplane stability, and in 1915 he gave the third Wilbur Wright Memorial Lecture on "The Rigid Dynamics of Circling Flight."

In that lecture one hurried look at the broadside of mathematical symbols and rows of integrals was sufficient to make most people turn against flying in any form. The JOURNAL report remarked that "Mr. F. W. Lanchester presided over a large and distinguished audience." Few in that audience expected to understand the equally distinguished professor's opening remarks. Yet few Wilbur Wright lecturers have begun more understandingly.

"I would like to say at once that I feel rather like the Girton graduate who, having given a lecture on the care of children, was asked by one of the audience whether she was married," he said, "and on replying in the negative was told that the questioner had thought so from the lecture."

Some of the things Lanchester then said from the Chair are worth repeating.

"The present occasion is one on which I may perhaps be permitted to offer my congratulations to the Aeronautical Society on its prosperity. I might almost say, in view of the vicissitudes through which the Society has passed, *on its existence*. It is certainly something of which any Englishman may be proud that this Society, the first of its kind to have been established in any part of the globe, will next year record its 50th anniversary. It is not easy today to over-appreciate the enthusiasm and prophetic foresight which led in 1866 to the founding of a Society destined only to see its objects fully achieved some forty years later. . . ."

Lanchester's own remarkable work was recognised by the Society in 1926 by the award of the next Gold medal.

The back numbers of the JOURNAL are full of interest, both for revealing the technical trends of the period, and also the personalities of the period. History to be worth while must be more personal than factual, and I speak with feeling having once learnt the dates of the Kings of England with no knowledge of what a king looked like or what he did in his spare time.

Almost exactly a year before Bryan's hopeful start to a Wilbur Wright Lecture, Lt.-Col. R. de Villamil, a good technical man with an unorthodox way of putting forward his ideas, took part in the discussion on a lecture on "The Measurement of Air Speed."

"We are told," he said, "that the total energy = potential energy + pressure energy + kinetic energy. In following the lecturer's argument I will change some of the names of the terms, thus:

Breakfast = bacon + eggs + tea

Now in the case under consideration the tea is not available (? tea-pot "broke itself").

Therefore

Breakfast = bacon + eggs

If there are no eggs, then

Breakfast = bacon

Also, if there is no bacon,

Breakfast = eggs

If, however, we substitute the values of bacon and eggs from formulæ (1) and (2) in the original formula, we get

Breakfast = breakfast + breakfast

But for the unfortunate accident to the tea-pot, we should have had

1 Breakfast = 3 breakfasts."

Villamil would have made a good Minister of Food.

G. L. O. Davidson, a member who had an idea for a helicopter with a hundred or more rotors, and was told by A. V. Roe that two were enough, in a lecture before the Society in 1898 on "The Flying Machine of the Future," said, "I have been consulting Nature for 16 years, but now the time has come for consulting engineers, but I find them more expensive!"

The cry these days is for more and more expensive engineers and less and less to be "informed by the light of Nature" of the sixteenth century philosopher.

Ah, well, one could go on reminiscing for pages. As I have been asked by the Council to write the History of the Society and with it some notes on its members and their achievements, I hope this letter will draw some material from those who alone can provide it, for it's later than you think.

In conclusion, as lecturers are so fond of saying and then talking for another twenty minutes, may I say a few words, following Lanchester, on how narrowly the JOURNAL has survived?

It was started with great courage and great foresight at the suggestion of Major B. F. S. Baden-Powell. On the death of the first secretary of the Society, F. W. Brearey, in 1896, after thirty years service, it was found that there was exactly £5 5s. 0d. in the bank and one or two small cheques which had not been presented. None of the Council knew the difficulties and dangers of publishing, so, to quote a notice sent out in January 1897, "The Council propose . . . to issue a Journal at least quarterly, containing not only reports of meetings of the Society, but original articles, reprints, and records of all that is going on at home and abroad in the subject of Aeronautics, and all news likely to be of interest to members."

A scrap of paper, found after the death of Baden-Powell, who acted as editor and paid so much of the losses, recorded that in the first three years the loss was just on £140, some subscribed for by members of Council, but most by Baden-Powell himself. Remember there was no aircraft industry, no aircraft, no benevolent government subsidising this and that, only hope, enthusiasm, and stout hearts. The number of paying members was just over 40 and the printing order was 300 a quarter.

Baden-Powell was a great correspondent on behalf of the JOURNAL and the Society. He wrote to everyone whose name was mentioned in the world's press as experimenting or being interested in the possibility of flight. It was through Baden-Powell's correspondence that the first authentic account appeared in the April 1904 JOURNAL of the historic flights at Kitty Hawk the previous December. It was sent by Orville Wright himself. The first paper Wilbur Wright ever published appeared in the JOURNAL for April 1901. Lawrence Hargrave, Samuel Langley, Octave Chanute, the brothers Wright, Pilcher, Lilienthal, J. W. Dunne, Santos Dumont, James Glaisher, Sir Hiram Maxim, Frost, Wenham, . . . pioneers, theoretical and practical, of airships, ornithopters, gliders, helicopters, kites, aeroplanes, . . . they are all to be found in these unique pages.

Octave Chanute was critically and practically helpful. Some of the early flow of ideas across the Atlantic began with Baden-Powell and his correspondents and many friendships were then made. In April 1898 Chanute wrote to Baden-Powell "You have been altogether too modest and tame in your announcement. The subscriber needs to be provided with a sharper stick. He wants to be told that experiments are now advancing the problem so fast that a Journal is necessary to keep up with it; that you have made arrangements to review what is being done

all over the world; that such care is used in editing as to furnish reliable information concerning the really meritorious proposals which are among those being exploited in the non-technical press, etc.; that if the reader is interested in the subject *this* is the Journal for him to take and that he had better order a full file from the beginning —as back numbers will soon be exhausted. Above all, remember that it takes two to six circulars (preferably different) to induce some persons to subscribe. . . . I enclose my subscription for 10 copies."

I like that last sentence. It shows the right way to criticise.

Following the end of the First World War aeronautics came down to earth, membership of the Society dropped severely, and the Finance Committee drew the attention of the Council to the urgent necessity of either increasing income or decreasing expenditure.

"On the question of reduction of expenditure," said Lt.-Col. H. T. Tizard (now Sir Henry Tizard), Chairman of the Council, at the Annual General meeting in 1925, "a glance at the Society's accounts will show you that there are only two items of expenditure that might conceivably be reduced to such an extent as to make income cover expenditure, namely, the cost of administration and the net cost of the Journal.

"The Council were emphatically of the opinion that the idea of reducing the cost of the Journal by limiting its size and circulation was not to be entertained. The utility, and the prestige, deservedly high, of the Society depends very largely on the standard set by its Journal."

In these days of financial difficulty the expression of opinion of the 1924 Council is more than ever cogent. That last paragraph should be printed in letters of gold ($2.80) for all to read, learn and inwardly digest.

The JOURNAL has never satisfied all the members all the time, and it is to be profoundly hoped that it never will. It is never as good as it was the moment you open your latest copy and never contains enough of the papers in which you are interested. It is too theoretical, it is too practical, it is too large, it is too small, it is not well illustrated, it has too many photographs, it is too impersonal, it is too personal, it is too American, it is too British . . . it is certain that when those who are responsible for it . . . and you who read this are one of them . . . believe it is the best aeronautical JOURNAL in the world, the world will tell them how right they are not.

Nevertheless, over the years, all fifty-six of them, every member can look back with great pride on the JOURNAL of the Royal Aeronautical Society. No aeronautical paper, no aeronautical journal, official or otherwise, in this country or out of it, can point to the galaxy of contributions from aeronautical stars of the first magnitude as can the Society's JOURNAL, nor to the value of its contents.

The Council of 1897 who founded it, named it simply

THE AERONAUTICAL JOURNAL

After fifty-six years it is more than ever worthy of such a proud title.

Sir, I am proud of the JOURNAL.

Every JOURNAL prints the following sentence or its equivalent. "None of the papers or paragraphs must be taken as expressing the opinion of the Council of The Royal Aeronautical Society unless such is definitely stated to be the case."

This letter is definitely stated not to be the case, for I am writing as an ordinary member of the Society.

I have only one apology to make, and that is about the length of this letter. My apology is that my letter is not long enough to pay proper tribute to the JOURNAL or to the Society. It never could be.

J. LAURENCE PRITCHARD (*Honorary Fellow*).

(Captain Pritchard has raised a number of issues in his letter. One hopes that many of those who have particular knowledge of those remarkable years 1904 *to* 1914, *and of the people who built so much for the future, will write in and give their reminiscences and comments on any points raised in Captain Pritchard's letter.*

By a coincidence, Brigadier-General Sir H. Osborne Mance, K.B.E., C.B., C.M.G., D.S.O., Companion, the oldest member of the Society, was asked if he would care to write something of his early memories of the Society and flying for the January 1953 JOURNAL. *Perhaps his letter will be an added encouragement to others.—Editor.)*

I think it was in 1894 when, as a cadet at Woolwich, I visited a demonstration of the Maxim flying machine in the park at Maxim's house. It was an extraordinary contraption with one central plane which, if I remember rightly, was octagonal in shape, and several supplementary planes which, I understood, had been successfully tacked on to increase the lift. The engine was, of course, steam. The machine ran on a rail track and to prevent it lifting there was a rail immediately above the track wheels. I believe on one occasion the machine actually rose and dislodged the upper rail. When I saw it they were giving 5/- rides over the length of the track; 5/- was scarce in those days! I have a notion that Maxim offered to allow anybody to fly the machine, but there were no takers.

My next practical contact with aviation was a free balloon flight from Earls Court on 5th November 1898. The balloon was piloted by Percival Spencer, and the other passengers were E. F. Knight, the famous "Times" war correspondent, and Mr. Swinburne of the "Daily Chronicle." The object of the flight was to test André's steering gear. The trip was interesting and amusing, but otherwise uneventful.

When Mr. Knight was sent to Cuba, "The Times" were good enough to invite me to participate on their behalf in a cross-Channel balloon flight to test the André gear over water. Unfortunately an obdurate colonel refused the necessary permission. The balloon which crossed the Channel in December 1898, while attempting to trail a rope, hit the sea twice. In July 1898 I wrote an article to "The Field" to prove mathematically that this was very likely to occur. Major Baden-Powell, after reading the article, invited me to lunch and persuaded me to join the Aeronautical Society in September 1898. A year or two later I paid a life subscription of ten guineas.

In, I think it was 1909, I went to Paris with a letter of introduction to Louis Bleriot, whom I found on the parade ground at Issy-les-Moulyneux, where he was expressing his candid views to two novices on their sinuous efforts on taxi-ing. He explained that he had not intended to fly that afternoon, but after demonstrating to his pupils how to taxi, he obligingly made two circuits of the area, flying very gingerly, at what would now be regarded as ridiculously low speed, about thirty feet from the ground, apparently with frequent adjustments of the controls.

I had nothing more to do with aviation until 1919, when the Air Squadron stationed at Paris for frequent journeys between Paris and London, informed me that I was their next best client after Winston Churchill and added hopefully that Winston Churchill had sent them a case of champagne!

H. O. MANCE (*Companion*).

THE LIBRARY

Reviews

WIND TUNNEL TECHNIQUE. Pankhurst and Holder. Pitman, London, 1952. 702 pp. 373 figures. 57s. 6d. net.

This book deals with a subject which has been almost entirely neglected by writers in the aeronautical field and it must therefore arouse considerable interest.

It is intended primarily for graduates who are entering the field of experimental aerodynamics, but it is also intended for the research worker and those engaged in wind tunnel testing. A considerable knowledge of both incompressible and compressible aerodynamics is assumed as, in general, the necessary formulæ are either quoted or only derived briefly.

The scope of the book can be seen from the chapter headings: Introductory. Wind Tunnel Design. Methods of Flow Visualisation. Measurements of Fluid Velocity. Wind Tunnel Balances. Aerodynamic Forces from Measurements of Pressure Distribution and Total Head Exploration. Manometers. Tunnel Interference Effects. Reduction of Observations. Special Measurements. Experimental Analogies. Notes on Models and Rigging. Appendices.

The book is very readable and well printed. There is a large number of figures, which are uniformly excellent in being clear and self-explanatory. At the end of each chapter an extensive list of references is given, which will make the book very valuable as a source book for more detailed or additional information.

It is inevitable in a book of this kind, because of the extraordinary volume of published material to choose from, that the critical reader of experience will find some instruments or methods ignored or summarily treated at the expense of others he considers to be of less interest. The criticisms made here are mostly of this character.

In the introductory chapter, the section on dynamical similarity is barely adequate and could have been enlarged, since dynamical similarity plays a vital part in experimental aerodynamics. The ideas underlying restricted dynamical similarity and the art of selecting the controlling variables could have been discussed and illustrated by reference to actual problems. The chapter on wind tunnel design deals with the design of both low-speed and high-speed wind tunnels in a fairly exhaustive manner and many examples of each are illustrated. It is a pity that cascade tunnels and the associated techniques are not dealt with more fully, but otherwise the treatment is excellent. The next chapter on flow visualisation is also a good account of the subject. In the chapter on the measurement of fluid velocity attention might have been called to the use of the sphere and the Conrad tube as yawmeters. The chapter on wind tunnel balances contains a representative selection of these instruments and is copiously illustrated. In the account on manometers too much space has been devoted to the Chattock manometer; there are others more suitable for general wind tunnel use, which approach the sensitivity of the Chattock gauge, and which are cheaper to construct, more robust and much easier to read. The chapter on wind tunnel interference is complete, but makes rather dull and heavy reading. It is somewhat surprising to find no mention of Simpson's rule in the chapter on reduction of observations! Under the heading of special measurements, the determination of humidity might have been mentioned as well as the " half wing " rig. The chapter on experimental analogies is out of place in this book, the title of which, in any case, is none too apt. The last chapter on models and rigging should prove invaluable to the wind tunnel operator and it is very well illustrated. In a book which runs to some 700 pages, Appendix 3, which gives conversion factors, could have been left out and this also applies to the date index of the British Reports and Memoranda series in Appendix 4.

The book well fulfils the needs of those for whom it was primarily intended and it will undoubtedly find a place on the bookshelves of all who are interested in experimental aerodynamics.—J. H. PRESTON.

MATERIALS HANDLING IN INDUSTRY. Electricity and Productivity Series No. 4. British Electrical Development Association, 1952. 142 pp. 109 illustrations. 8s. 6d. net.

Since all manufacturing industries handle raw material and then, having converted it into a product, handle it again to dispose of it, this book has some lessons of interest for everyone.

This small book—it contains only 142 pages but has 109 illustrations—is a useful contribution to the scanty literature available in this country.

Brief but clear descriptions are given of all kinds of mechanical handling equipment from the simple skids and stillages to the most complex conveyer belt systems.

Fork lift and other types of truck are dealt with as well as cranes, gantries and many hydraulic, pneumatic or mechanical devices to aid the materials handling man.

This author rightly bases his philosophy on the statement " Every time material is handled, something is added to the cost and nothing to its value." This, added to the less obvious fact that " Every time material is held in one place for a year it costs about one extra fifth of its initial purchase cost " are the major material handling problems. How to combine these two facts in the optimum fashion is a matter of careful economic study. Unfortunately, while this book shows one how to move materials it gives less instruction on the subject of the cost of doing it, so that alternatives can be properly selected. This is a common fault with books on the subject and somewhat detracts from its usefulness, especially as it may give the impression that all the systems are improvements over the simple " old-fashioned " ones.

Conveyers and mechanical trucks are expensive in capital and require gangways which take up floor space. This may finally cost more than the labour cost saved. Therefore, careful, conservative costing is needed before adopting any scheme and one is left with an unsatisfied thirst for knowledge of many economic factors after reading this otherwise useful book.—J. V. CONNOLLY.

THE ESSENTIALS OF FLUID DYNAMICS. L. Prandtl. Blackie and Son Ltd., 1952. 452 pp. Index. Illustrated. 35s. net.

This book is a translation by Miss W. M. Deans of the 1949 edition of the author's "Führer durch die Strömungslehre," and its purpose, as stated in the author's preface, is "to be a guide to the reader, to the beginner and the advanced student as well as to the expert in an adjoining field of research. To achieve this, complex mathematical analysis has been avoided as far as possible, and in general formulæ take second place, the principal object being the awakening of clear, intuitive apprehension." Its purpose is abundantly achieved.

The work is divided into five chapters, which between them cover almost every aspect of fluid mechanics. The first chapter deals with fluids in equilibrium, both under the action of gravity and under more general fields of force; there is also a section on surface tension. The second chapter treats the kinematics and dynamics of frictionless liquids in irrotational and rotational motion, including wave motion on the surface of a liquid. Motion of viscous liquids is treated in the third chapter, and the topics include dynamical similarity, boundary layers, turbulence, eddy formation, secondary flows, lubrication, pipe flow, aerofoil and propeller theory, hydraulic machinery, and experimental methods. In the fourth chapter, on the dynamics of gases, the author treats the propagation of small disturbances, one-dimensional steady flow, shock waves, subsonic and supersonic flow in more than one dimension, and experimental techniques. The last chapter is devoted to miscellaneous topics and contains accounts of cavitation, water hammer, accelerated flow, rotating bodies and rotating reference frames, meteorological phenomena, and heat transfer, to mention only the more important subjects. References to the literature on the various matters treated are given as footnotes to the text, and there is a supplementary bibliography at the end. The book is well indexed.

As expected in a work by this distinguished author, the exposition is clear and stimulating, and some credit for this must go to the translator. The book is highly recommended to all students of fluid mechanics.—G. N. WARD.

ROCKET PROPULSION—WITH AN INTRODUCTION TO THE IDEA OF INTERPLANETARY TRAVEL. Eric Burgess, F.R.A.S. Chapman & Hall, 1952. 235 pp. 56 figures. 21s. net.

To quote from its dust jacket, this book: "Is presented, not only as an introduction and fascinating story for the layman, but also as a useful work of collated data for students and specialists who require a handy reference book on the many aspects of the science of rocketry and its ultimate developments." Its author is a prominent member of the British Interplanetary Society, well known for his popular lectures and articles on the same subject. Unfortunately, his present work can hardly be recommended to the second group of readers mentioned above. It might be better received by the large and growing number of laymen interested in rockets and space flight, though, for such an audience, its scientific sights should probably have been set considerably lower.

Messrs. Chapman and Hall have made a better job of the book's production than the author has, in his selection and presentation of material. The phraseology and general approach is often quaintly unconventional, in a way which could be misleading; worse still, it is sometimes inaccurate. One is generally conscious that the author is writing about highly technical matters of which he has no professional experience. Discussions of these follow long explanations, in words, of the more elementary laws of mechanics.

Another example of lack of balance in the book is the disproportionate attention paid to the work and ideas of many small pre-war rocket societies. A few of these—the V.f.R., A.R.S., and B.I.S.—had a real technical and historical importance, but some of those dealt with by Mr. Burgess were (though he does not make this clear) of a merely juvenile character.

In Fig. 4, a small motor of 100 lb. thrust, produced by the present Pacific Rocket Society in the U.S.A., is used to illustrate "the compact form . . . of a modern rocket unit." This is rather like citing a toy aeroplane as an example of up-to-date aerodynamics. Although many of the other illustrations are admittedly better chosen, this one almost epitomises the style of the volume. It is, one regrets to say, merely a brave try by a talented amateur, unaware of his limitations. In this modern world, the amateur's day is just about over, at least in the fields of the pure and applied physical sciences.—A. V. CLEAVER.

AIR WAR AND EMOTIONAL STRESS. Irving L. Janis. McGraw-Hill, New York, 1951. 280 pp. 42s. 6d. net.

This book is not concerned with the emotional stress experienced by the aviator, but that which he inflicts by bombing. The author, as an academic psychologist, proceeds to collect and analyse such factual data as are available, from the experiences of the Second World War, for estimating the emotional reactions of individuals and groups to the threat and actuality of air attack. As one of his main objects is to procure knowledge which will be of value in developing effective civil defence policies in the future, he naturally begins with an account of the reactions to atomic bombing at Hiroshima and Nagasaki, to which the first three chapters are devoted. Although the data for this enquiry are admittedly scanty, some interesting conclusions are reached. The magnitude of the initial catastrophe, involving destruction, death and mutilation on an unprecedented scale, had a brief, paralysing effect, but recovery from this was rapid, and the morale of the people in and around the target cities did not fall below the rest of Japan. Psychoses, traumatic neuroses and other severe psychiatric disorders appear to have been a rare occurrence following the atomic bomb attacks. This agrees with the reports of investigators in Great Britain and Germany on the effects of ordinary high explosive bombing.

A study of the factors contributing to the excitation and inhibition of fear, and the fluctuations of individual and group morale shows that the psychology of fear in the civilian is much the same as in the combatant, although the latter has the great advantage of having an outlet for aggressive feeling.

The later chapters are concerned with the principles and practice of psychological defence measures. It is argued, for example, that a public address system should be installed in each potential disaster area, so that survivors should be told what to do immediately after the explosion. The psychological value of shelters, rescue units, and anxiety-reducing information are among the topics discussed.

This book is based upon factual analysis and is written clearly and without emotion. It should be of great value to all who may be called upon to prepare civil defence against air war in Great Britain.—CHARLES SYMONDS.

BUCKLING STRENGTH OF METAL STRUCTURES. Friedrich Bleich. McGraw-Hill, New York, 1952. 508 pp. 263 figures. £4 5s. 0d. net.

In the opinion of the reviewer, this book is the most important to be written about elastic stability since the publication—also as an Engineering Societies Monograph—of Timoshenko's classic work *Theory of Elastic Stability*. It is lucidly written, beautifully produced, and approaches the subject from the essentially practical standpoint of the practising engineer.

As the work was sponsored by the Bureau of Shops of the U.S. Navy Department, it has been written with the needs of naval architects and engineers primarily in mind. But the value of the book is by no means limited to these two special groups of people, as much of the contents is relevant to nearly all branches of structural engineering, including in particular that of aircraft structures.

Two features which deserve special mention are the following. First, the care with which different theories are compared and contrasted, and the thoroughness with which the basic assumptions and their range of validity are examined and explained. Second, the amount of attention paid to what happens outside tne purely elastic range.

From the standpoint of the aeronautical structural engineer, *Buckling Strength of Metal Structures* provides a comprehensive treatment of the stability problems associated with columns and flat sheets, but does not cover *in sufficient detail* either the stability of curved sheets (considered as isolated components), or the stability of sheet-stringer combinations.

It is fair to say that for the special purpose for which it was written, *i.e.* for designers and engineers engaged in naval construction, Dr. Bleich's book is admirable; for those whose interests lie in other branches of structural engineering it is well worth having.—D. M. A. LEGGETT.

TEXT BOOK OF PHOTOGRAMMETRY. Dr. M. Zeller. English translation from the German original by E. A. Miskin and R. Powell. H. K. Lewis and Co. Ltd., London, 1952. 274 pp. Illustrated. 50s. net.

Dr. Zeller is well known in European photogrammetric circles, being Director and Professor of the Photogrammetric Institute of the Swiss Federal Institute of Technology at Zürich. He has conducted eight special international courses in photogrammetry and has contributed much to the literature of the subject.

His book is a comprehensive treatise on the basic theory and use of Wild cameras and stereoscopic plotting machines and, within the field which he has chosen, it is admirable and authoritative. There are four chapters. The first deals briefly with camera lenses, photography and stereoscopy, and the second with terrestrial photogrammetry, including an excellent section on field work. Sections are also devoted to ballistic surveys, close range photogrammetry for police, medical and other work, and micro-photogrammetry.

The third chapter, taking up half the book, is entitled Aerial Photogrammetry. It includes a full description of the theory and methods of using Wild equipment to map from aerial photographs, from the photographic processes and flight planning to the plotted map, with sections on the ground control necessary, on rectification and aerial triangulation. From this the reader may deduce much of the information necessary to understand and use other similar plotting machines. Chapter four is a short summary of the applications of aerial photogrammetry, including land registration, geological mapping and photo-plans.

The application of the theory of errors is emphasised and fully discussed throughout, but it is unfortunate that one of the results of this is that Dr. Zeller makes virtually no mention of the Multiplex, trimetrogon and slotted template apparatus and methods of mapping. For, to quote from his preface: ". . . On the strength of the knowledge thus gained, the treatment of apparatus and mapping methods, demonstrably inadequate technically and consequently economically unsatisfactory, has been dispensed with." Not all his readers would agree that these remarks apply fully to the methods and equipment just mentioned, which are in wide use at present.

A further omission is in the short section on photographic materials. It is stated that film would be preferred to plates for aerial photogrammetry if it were more stable, differential distortion being of the order of 0·1 per cent., which cannot be tolerated. But no mention is made of photogrammetric methods to overcome the effects of this distortion, and research in this field is being actively prosecuted at present.

The text has been revised and well re-written in the English idiom by Dr. E. A. Miskin, and English-speaking surveyors will be much indebted to him for making available this important account of continental method and practice. There is a bibliography of 85 items, almost all of which are by European authors but, unfortunately from the point of view of the average English reader, in the German language.—A. R. ROBBINS.

A SELECTION OF TABLES FOR USE IN CALCULATIONS OF COMPRESSIBLE AIRFLOW. Compressible Flow Tables Panel of the Aeronautical Research Council. Oxford University Press, 1952. 143 pp. Tables. 40s. net.

There has long been a need for a collection, in one volume, of the many tables that workers in the field of compressible air flow like to have at hand. This need has been recognised by the Aeronautical Research Council, who set up in 1948 a Panel to undertake the task of preparing authoritative tables and graphs. The present volume of tables is the first product of the Panel's labours: a companion volume of graphs will follow shortly.

The tables are grouped into six sections. In Section I are given tables of the many quantities that occur in isentropic air flow. Section II gives tables of quantities that occur in the study of supersonic air flow by the method of characteristics and Section III gives tables of quantities associated with normal and oblique shocks. Experimental workers will find Section IV particularly useful, as tables are given of Mach number in terms of the following arguments: static pressure/total pressure, static pressure/pitot pressure, and pitot pressure/total pressure. Section V gives tables of fractional powers of x, and powers of $\sqrt{(1-x^2)}$. The former are intended to facilitate the raising of numbers to powers that are functions of γ (taken as 1·4 throughout), and the latter to aid the computation of $\sqrt{(1-M^2)}$ and its powers. (It is a pity that equal facilities are not extended to $\sqrt{(M^2-1)}$. Finally in Section VI are given a collection of miscellaneous tables, including tables to assist in the computation of Reynolds number, tables of derivatives of flow functions with respect to γ, and tables of the standard atmosphere.

The number of decimal places or significant figures is generally five and, for most tables, first differences are given, italics being used to indicate when linear interpolation would lead to reduced accuracy. Considerable trouble has been taken with presentation. There is full cross-referencing between tables and the relevant formulæ, and one is assisted in finding one's way about by thumbing marks on the pages. The typography is excellent. On

the whole this volume represents a job of work well done, and it follows that any adverse criticism is on minor matters. For example, in Section I the flow quantities are tabulated from $M=0$, by (0·01) up to 0·5, by (0·001) up to 1, by (0·01) up to 5; the change in the interval of the argument right in the middle of the transonic range is a little unfortunate. Further, the determination of Reynolds number (Section VI) unnecessarily requires the determination of an intermediate quantity. Finally, although most of the basic quantities are quoted to six significant figures, the absolute zero of temperature is quoted to only three figures, although quantities which depend upon it, such as the gas constant, are quoted to five figures. Nevertheless, the book can be strongly recommended, and the volume of graphs is eagerly awaited.—C. H. E. WARREN.

D.C. POWER SYSTEMS FOR AIRCRAFT. R. H. Kaufmann and H. J. Finison. John Wiley. Chapman & Hall, London. 1952. 206 pp. Diagrams. 40s. net.

During the Second World War, the size and complexity of aircraft electric power systems increased to such a degree that more study of the behaviour of the systems as a whole became necessary. System-Engineering, as practised by the authors, became the name adopted in U.S.A. for the work involved in predicting the performance of aircraft electrical systems and in verifying the theory by laboratory and flight tests.

This work, done at General Electric, Schenectady, and at Wright Field, forms the basis for this excellent book. Total generator capacity has increased from a maximum of six kilowatts before the war to nearly 100 kilowatts for many modern military bomber aircraft, so the need for a book of this type is apparent.

Chapter one covers the uses to which electricity can be put on modern aircraft and outlines the advantages of the utilisation of electrical energy over other systems. The severity of the operating conditions is rightly emphasised.

Although the book is primarily devoted to 24 volt D.C. systems, a table gives the A.I.E.E. voltage rating for medium-voltage systems. This is given as $125\pm0/15\%$ volts, but it is understood that following Anglo-American collaboration, a voltage of 112 ± 3 volts has been agreed upon.

Chapters two and four cover very adequately the characteristics of D.C. generators and regulators, the transient volt-ampere characteristics of generators being clearly shown. Rightly the authors realise the importance of the stability of voltage regulators. They deal mainly with the carbon-pile type, which they should have attributed to the British inventor, Newton. Some comparisons with the Tirril type would have been interesting.

For the first time in a book, the influence of temperature on the internal resistance of storage batteries is given.

In outlining the advantages of the auxiliary power plant over generators driven by main engines, the authors have not mentioned the weight reduction in both generator and regulator which can result from the constant speed of the prime mover. Such advantages could also result from the use of a constant speed drive associated with main engines and, while it is realised that such drives were designed primarily for A.C. generators, they can still be attractive with D.C. machines, particularly with large speed range and attendant complications in D.C. generator design.

The illustrations in this chapter show piston engine units, but the authors have no doubt considered the use of small gas turbines for this purpose. The work of Air-Research and Solar Aircraft could have been mentioned.

Effects of short-circuit and complete circuit protection, including its application, occupy considerable space, emphasising the importance of this subject. On some modern systems, fault currents up to 10,000 amperes have to be dealt with and the importance of protective devices which will deal with such conditions without closing down the complete system cannot be over-stated.

The book should appeal to designers of aircraft generators and protective systems, and to electrical engineers associated with the Project Department of aircraft constructors. A minor criticism is the omission from the references of papers on this subject emanating from this side of the Atlantic.—R.H.W.

New Books Received

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Reports

AERODYNAMICS

Boundary Layer

Solutions of laminar-boundary-layer equations which result in specific-weight-flow profiles locally exceeding free-stream values. W. B. Brown and J. N. B. Livingood. N.A.C.A. T.N. 2800.

Revised solutions of the laminar-boundary-layer equations for cases which involved cooling at the wall combined with large pressure gradients in the main stream produced specific-weight-flow profiles which locally exceeded free-stream values. Heat-transfer and friction coefficients, boundary-layer thicknesses, and velocity, temperature, and specific-weight-flow distributions resulting from the revised solutions are presented.—(1.1).

Compressible Flow

Conical flow as a result of shock and boundary-layer interaction on a probe. J. Lukasiewicz. R. & M. 2669.

The formation of a conical shock and a conical region of flow separation originating from the tip of a thin traversing tube was observed in a supersonic tunnel as a result of interaction of a strong shock with the boundary layer on the tube surface. The angles of the conical shock and separation surfaces and the static pressure in the separation region are in good agreement with the theoretical conical flow solutions.—(1.2).

Some measurements at low supersonic speeds by a method for continuous variation of the Mach number. G. Drougge. F.F.A. Report 42.

A previously described method for continuous variation of the Mach Number in a supersonic nozzle by means of a movable plate is further developed. The plate is used as a holder for a three-component balance for half-models. The test section and the movable plate arrangement are described in detail and also given are the results of the calibration of the test section. Finally some results from three-component measurements on some wings of simple plan forms are presented. The Mach Number range obtained is $M = 1{\cdot}07 - 1{\cdot}40$.—(1.2).

Airfoil profiles for minimum pressure drag at supersonic velocities—application of shock-expansion theory, including consideration of hypersonic range. D. R. Chapman. N.A.C.A. T.N. 2787.

A theoretical investigation employing shock expansion theory is made of the aerofoil profile having minimum pressure drag at zero lift for various given auxiliary conditions. Curves are presented to facilitate the application of the theory, and typical optimum profiles are illustrated.—(1.2).

A study of the transient behavior of shock waves in transonic channel flows. R. V. Hess. N.A.C.A. T.N. 2797.

The accuracy of the result obtained in a fundamental paper by Kantrowitz (N.A.C.A. T.N. 1225) that a small short-time lowering of the back pressure in steady, shock-free, transonic diffuser flow causes a stationary or trapped shock to form near the critical sonic channel throat is investigated by considering the contribution of a higher-order term in the short-time calculations which was neglected in Kantrowitz's paper.—(1.2).

Investigation with an interferometer of the flow around a circular arc airfoil at Mach numbers between 0·6 *and* 0·9. *G. P. Wood and P. B. Gooderum. N.A.C.A. T.N.* 2801.

The flow around a 12 per cent. thick circular-arc aerofoil at zero incidence was observed by use of an interferometer for small increments of free-stream Mach number from 0·609 to 0·896 with laminar and turbulent boundary layers. Mach number contours in the flow field and Mach number and pressure distributions on the airfoil were obtained. Conditions were determined along and at the bases of the shock waves that interacted with the turbulent boundary layer on the aerofoil.—(1.2).

On the calculation of flow about objects travelling at high supersonic speeds. A. J. Eggers, Jr. N.A.C.A. T.N. 2811.

A procedure for calculating three-dimensional steady and nonsteady supersonic flows with the method of characteristics is developed and discussed. An approximate method is deduced from the characteristics method and shown to be of practical value at high supersonic speeds.—(1.2).

Fluid Dynamics

The numerical solution of two-dimensional fluid motion in the neighbourhood of stagnation points and sharp corners. L. C. Woods. R. & M. 2726.

Methods are given of dealing with singularities of functions satisfying certain two-dimensional partial differential equations. For a numerical solution the differential equations are replaced by difference equations on a square mesh. Log $(1/q)$ where q is the velocity, becomes infinite at stagnation points, sharp corners, sinks, etc., while the conjugate function θ (flow direction) becomes multi-valued. The method consists in finding a series expansion for the function (log $1/q$ or θ) in the neighbourhood of the singularity. This expansion is then used to find relationships between the function values at points of the mesh adjacent to the singularity. A method of working directly in the transformed flow plane (in which the aerofoil is a slit), and thus avoiding irregular squares on the boundary, is also given. The method is developed for incompressible flow, but an approximation suitable for compressible flow is given.—(1.4).

Use of a consolidated porous medium for measurement of flow rate and viscosity of gases at elevated pressures and temperatures. M. B. Biles and J. A. Putnam. N.A.C.A. T.N. 2783.

Use of a consolidated porous medium as a gas-metering device and for determination of gas viscosity has been investigated over a moderate range of temperature and pressure. The geometry of such elements permits an appreciable range of gas flow rate to be metered with small, accurately controlled, pressure drops. The advantages of such a device warrant its use as a laboratory instrument. Results of the flow tests have been employed in the determination of the viscosity of air up to approximately 900 pounds per square inch absolute at the two test temperatures of 75° and 517° F.—(1.4).

A method for the determination of the time lag in pressure measuring systems incorporating capillaries. A. R. Sinclair and A. W. Robins. N.A.C.A. T.N. 2793.

A method is presented for the determination of the time lag in pressure measuring systems incorporating capillaries; this method is a convenient and systematic means of selecting, designing, or redesigning a pressure measuring system to meet the time requirements of a particular installation. Experimental data are shown and a step-by-step sample application is presented.—(1.4).

A comparison of two methods of linearized characteristics for a simple unsteady flow. R. D. Sullivan. N.A.C.A. T.N. 2794.

Two methods of using the concept of linearised characteristics are derived for the one-dimensional unsteady flow in a tube that is rotated about an axis perpendicular to the axis of the tube. One of the methods corresponds to that used by Ferri in his basic work on the subject. Solutions are made by both methods for boundary conditions that allow analytic solutions. Comparisons shows that both methods give the same results but there are significant differences in their application.—(1.4).

Comparison of two- and three-dimensional potential-flow solutions in a rotating impeller passage. G. O. Ellis and J. D. Stanitz. N.A.C.A. T.N. 2806.

A solution is presented for three-dimensional, incompressible, nonviscous, potential flow in a rotating impeller passage with zero through flow. The solution is obtained for a conventional impeller with straight blades but with the inducer vanes removed and the impeller blades extended

NOTE:—*The figures in parentheses at the end of each summary are for internal use.*

upstream parallel to the axis of the impeller. By superposition of solutions two additional examples are obtained for different ratios of compressor flow rate to impeller tip speed. The three-dimensional solutions are compared with corresponding two-dimensional solutions.—(1.4).

INTERNAL FLOW

Concerning the annular air intake in supersonic flight. I. M. Davidson and L. E. Umney. R. & M. 2651.

The stability of an annular air intake at a Mach number of 1·4 and with Reynolds numbers of about $1{\cdot}5\times10^6$ is considered in detail and a method is described whereby the experimental results might be extrapolated for preliminary full-scale design purposes.—(1.5).

One-dimensional analysis of choked-flow turbines. R. E. English and R. H. Cavicchi. N.A.C.A. T.N. 2810.

Flow conditions internal to choked-flow turbines were subjected to a one-dimensional analysis. Factors affecting the design, operation and manufacture of such turbines were investigated. Criteria are presented which will aid in analysis of test data from such turbines. The effect of turbine-stator adjustment on internal flow conditions was investigated for one application of turbine stator adjustment.—(1.5).

LOADS

Model tests with flow on the Gloster F.9/40 with H.1 nacelles (Meteor II). J. S. Thompson, C. M. Fougère and E. G. Barnes. R. & M. 2517.

Model tests at high jet flows were required for the estimation of stability. Measurements of lift, drag, pitching and yawing moments were made for jet flows up to an exit v/V of 4·5 and at various wind speeds.—(1.6).

STABILITY AND CONTROL

The effects on dynamic lateral stability and control of large artificial variations in the rotary stability derivatives. R. O. Schade and J. L. Hassell, Jr. N.A.C.A. T.N. 2781.

The results of an experimental and theoretical investigation of the effects of large artificial variations of four rotary stability derivatives on the dynamic lateral stability and control of a 45° swept-back wing aeroplane model are presented. Calculations of period and damping and of the response to rolling and yawing disturbances are also presented.—(1.8).

THERMO-AERODYNAMICS

Simple graphical solution of heat transfer and evaporation from surface heated to prevent icing. G. H. Gray. N.A.C.A. T.N. 2799.

Equations expressing the heat transfer and evaporation from wetted surfaces during ice prevention have been simplified and regrouped to permit solutions by simple graphical means. Working charts for quick and accurate anti-icing calculations are also included.—(1.9).

WINGS AND AEROFOILS

Tests in the compressed air tunnel on two aerofoil sections having a large scale effect on $C_{L\,max}$ at a critical Reynolds number. C. Salter, Miss H. M. Lee and Miss R. C. Owen. A.R.C. Current Paper 92.

The report gives results of tests on two "constant velocity" aerofoil sections, 9 per cent. and 11 per cent. thick respectively, and of aspect ratio 6, over a range of R of $0{\cdot}3\times10^6$ to $7{\cdot}5\times10^6$.—(1.10).

Note on profile drag calculations for low-drag wings with cusped trailing edges. R. C. Lock. R. & M. 2419.

In R. & M. 1838 calculations of profile drag were made based on wing sections of conventional design, and were later extended in an Addendum to "low-drag" wing sections with convex trailing edges. Calculations were made on sections of more recent design with cusped trailing edges. Calculations were made on sections of the N.A.C.A. 65-family of thickness 0·12c and 0·23c with maximum thickness at 0·4c from the leading edge, over a range of Reynolds number and position of the transition points.—(1.10).

Velocity distribution on straight and sweptback wings of small Thickness and infinite aspect ratio at zero incidence. S. Neumark. R. & M. 2713.

A solution by H. Ludwieg, giving the velocity distribution in the central section of a thin swept-back wing of infinite aspect ratio with a biconvex profile at zero incidence, has been found erroneous. In connection with this problem, the approximate method of sources and sinks for determining velocity distribution on straight and swept-back wings is critically examined, its limitations established, and proper ways of its application to three-dimensional problems indicated. A correct solution of Ludwieg's problem is found, and generalised to give the velocity distribution over the entire wing. The method is further extended to cover a wide class of thin symmetrical wing profiles, those with rounded leading edge being, however, often intractable by this particular method.—(1.10).

Integrals and integral equations in linearized wing theory. H. Lomax, M. A. Heaslet and F. B. Fuller. N.A.C.A. Report 1054.

The formulas of subsonic and supersonic wing theory for source, doublet, and vortex distributions are reviewed, and a systematic presentation is provided which relates these distributions to the pressure and to the vertical induced velocity in the plane of the wing. Concepts suggested by the irreversibility of order of integration are shown to be useful in the inversion of singular integral equations when operational techniques are used.—(1.10).

Theoretical antisymmetric span loading for wings of arbitrary plan form at subsonic speeds. J. DeYoung. N.A.C.A. Report 1056.

A simplified lifting-surface theory that includes effects of compressibility and spanwise variation of section lift-curve slope is used to provide charts with which antisymmetric loading due to arbitrary antisymmetric angle of attack can be found for wings having symmetric plan forms with a constant spanwise sweep angle of the quarter-chord line. Aerodynamic characteristics due to rolling, deflected ailerons and sideslip of wings with dihedral are considered. Solutions are presented for straight-tapered wings for a range of swept plan forms. *It should be noted that this report supersedes N.A.C.A. T.N.* 2140.—(1.10).

On the design of airfoils in which the transition of the boundary layer is delayed. I. Tani. N.A.C.A. T.M. 1351.

A method is presented for designing suitable thickness distributions and mean camber lines for aerofoils permitting extensive chordwise laminar flow. Wind tunnel and flight tests confirming the existence of laminar flow; possible maintenance of laminar flow by area suction; and the effects of wind tunnel turbulence and surface roughness on the promotion of premature boundary-layer transition are discussed. Estimates of profile drag and scale effect on maximum lift of the derived aerofoils are made.—(1.10).

Flow studies in the vicinity of a modified flat-plate rectangular wing of aspect ratio 0·25. *W. H. Michael, Jr. N.A.C.A. T.N.* 2790.

Studies were made of the flow in the vicinity of a modified flat-plate rectangular wing of aspect ratio 0·25 by the use of photographs of a tuft grid located at various chordwise positions on the wing and behind the wing, supplemented by wake studies with a yaw-head pitot-tube installation. Evaluations were made concerning the rolling-up of the trailing vorticity, vorticity distribution in the wake, chordwise growth of lift, and locations of the vortex cores.—(1.10).

Effects of wing sweep on the upwash at the propeller planes of multi-engine airplanes. V. L. Rogallo. N.A.C.A. T.N. 2795.

An analysis is presented to give a qualitative picture of the effects of wing sweep on the upwash at the propeller planes of multi-engine aeroplanes. In order to provide a basis for judging effects of sweep, comparisons are made of the upwash and upflow angles at the propeller planes of two hypothetical aeroplanes of the high-speed long-range type, one having an unswept wing and the other a swept-back wing. The effects of compressibility are considered. Charts are provided to enable the prediction of upwash in the chord-plane region ahead of wings of various plan forms.—(1.10).

Helicopter Aerodynamics

Comparison of helicopter rotor model tests of aerodynamic damping with theoretical estimates. G. J. Sissingh. A.R.C. Current Paper 98.

The report deals with the aerodynamic damping of a rotor oscillating in pitch (or roll) and is mainly concerned with the comparison between theory and experiment. Both the free and forced oscillations of a rotor system pivoted below the rotor centre are investigated.—(1.11).

Helicopter behaviour in the vortex ring conditions. W. Stewart, A.R.C. Current Paper 99.

A region of roughness, associated with the airflow conditions of the vortex ring state, occurs when a helicopter is operating in vertical or near vertical descents in the range of about 500 and 1,500 ft./min. The turbulent circulating air and the rapid changes in local velocities in this flow pattern can cause serious helicopter handling difficulties. This could cause concern in a slow steep approach, particularly under instrument flying conditions. This report describes flight experience in the vortex ring conditions with the Sikorsky R-4B, R-6 and S-51, Bell 47 and Bristol 171 helicopters. It is shown that the helicopter behaviour varies from a mild wallowing on the best type to a complete loss of control on the worst case. These effects are due to the turbulent flow changes in the vortex ring and the loss of control is thought to be caused by large changes in pitching moments on the fuselage with small displacements of the helicopter relative to the unusual flow pattern.—(1.11).

The effect of induced velocity variation on helicopter rotor damping in pitch or roll. G. J. Sissingh. A.R.C. Current Paper 101.

The present investigation is a continuation of a recent report by K. B. Amer on the aerodynamic damping of a rotor with centrally arranged flapping hinges in a steady pitching or rolling motion. It considers the effect of variation in the induced velocity due to the changes in the distribution of the thrust around the rotor disc. The results are compared with the flight measurements given in Amer's report and the agreement is good.—(1.11).

AEROELASTICITY

*Experimental determination of the aerodynamic coefficients of an oscillating wing in incompressible two-dimensional flow. Part IV. Calculation of the coefficients. H. Bergh and A. I. Van de Vooren. N.L.L. Report F.*104.

Experimental aerodynamic coefficients for a sinusoidally oscillating wing, calculated from the measurements described in the reports F. 101, F. 102 and F. 103, are presented. The coefficients are given for values of the reduced frequency ω (referred to semi-chord), varying from 0·08 to 1·0. In general, the results are in good agreement with the theory, though systematic deviations exist, especially for higher ω-values. The influence of the Reynolds number is negligible, provided that boundary layer transition is fixed on the aerofoil by a turbulence wire during the measurements.—(2).

*An approximate theory of the oscillating wing with control surface in a compressible subsonic flow for low frequencies. E. van Spiegel. N.L.L. Report F.*114.

An approximate theory is developed for a thin two-dimensional aerofoil with control surface oscillating with low frequencies in a compressible subsonic flow. The approximation is obtained by neglecting the wave-term in the differential equation determining the velocity potential. In this report only the first approximation is derived.—(2).

On the theory of slowly oscillating delta wings at supersonic speeds. S. B. Berndt. F.F.A. Report 43.

To investigate the applicability of the quasi-stationary approximation (obtained by disregarding time derivatives in the differential equations but not in the boundary conditions), a method has been obtained by which the lift distribution for slow harmonic oscillations can be calculated. The quasi-stationary approximation is seen to be satisfactory only for oscillations which maintain the chords parallel to the undisturbed flow. The method is applied to the narrow rigid triangular wing, for which the first approximation (already known) can be expressed by well-established steady solutions.—(2).

Flight investigation of transient wing response on a four-engine bomber airplane in rough air with respect to centre-of-gravity accelerations. H. C. Mickleboro, R. B. Fahrer and C. C. Shufflebarger. N.A.C.A. T.N. 2780.

The results of a flight investigation on a four-engine bomber aeroplane to determine the transient-response effects of wing flexibility in gusts showed that the measured acceleration increments at the centre of gravity were approximately 28 per cent. higher than the true aeroplane acceleration increments. This relationship appeared to be only slightly affected by the variations in speed and weight covered by the test conditions.—(2.0 × 32.1.2).

FLIGHT TESTING

Notes on the derivation of true air temperature from aircraft observations. D. D. Clark. A.R.C. Current Paper 90.—(12.1).

An assessment of the probable causes of variation of the speed correction coefficient of aircraft thermometers. A.R.C. Current Paper 91.—(12.1).

FUELS AND LUBRICANTS

Effect of aliphatic halogen compounds on carbon deposition from aircraft gas turbine fuels. W. Sacks and M. T. I. Ziebell. N.A.E., Canada, Note 10.

The results of experiments on the effect of aliphatic halogen compounds on the tendency of aircraft gas turbine fuels to deposit carbon are presented. The deposition on an air-swirler plate, surrounding a miniature pressure atomizer, was measured after combustion in a quartz-tube chamber. The experiments were carried out at air/fuel ratios (wt.) of 6 to 15. Iodides, bromides and chlorides representing a number of different types of molecular structures were investigated. Two turbine fuels were used; a wide boiling range fuel (b.p. 90-522° F.) and a kerosine (b.p. 328-512° F.).—(13.1 × 31.1).

N.A.C.A. investigation of fuel performance in piston-type engines. H. C. Barnett. N.A.C.A. Report 1026.

A compilation of many of the pertinent research data acquired by the N.A.C.A. on fuel performance in piston engines. The following specific subjects are discussed: High-speed photographic studies of knocking combustion, by C. David Miller; correlations of knock-limited performance data; anti-knock performance scales; pre-ignition; hydrocarbons and ethers as anti-knock blending agents; aromatic amines as fuel additives; tetraethyl lead as a fuel additive; anti-knock blending characteristics of fuels; fuel volatility; and internal cooling.—(13.1).

Effects of solvents in improving boundary lubrication of steel by silicones. S. F. Murray and R. L. Johnson. N.A.C.A. T.N. 2788.

Because of the known synthetic fluids, silicones best satisfy the viscometric requirements for lubricants for turbine engines, a study was conducted to establish the effect of solvents on boundary lubrication by silicones. Boundary-lubrication data were obtained which are considered substantiating evidence for a hypothesis that, in solutions of solvents blended with silicones, the silicones form a closely packed and oriented adsorbed film on ferrous surfaces. The solutions reduced friction and prevented surface failure even when the solvent as well as the silicone was an extremely poor lubricant.—(13.2).

MATERIALS

The effect of strain on strain ageing. C. J. Osborn. A.R.L., Australia, Report S.M. 196.

By means of carefully controlled hardness tests on a low carbon steel aged at various temperatures after straining plastically 5, 10 and 20 per cent., it is shown that both the time necessary for complete ageing and the activation energy of the strain ageing process are independent of the strain. The ageing rate in the early part of the process is increased by greater initial strain.—(20.2).

Correlation of tensile strength, tensile ductility, and notch tensile strength with the strength of rotating disks of several designs in the range of low and intermediate ductility. A. G. Holms and A. J. Repko. N.A.C.A. T.N. 2791.

Burst tests were conducted on several designs of sound discs and discs with defects and results were compared with tensile strength, tensile ductility, and notch tensile strength.—(20.2.2).

An experimental investigation of the behavior of 24S-T4 aluminum alloy subjected to repeated stresses of constant and varying amplitudes. H. F. Hardrath and E. C. Utley, Jr. N.A.C.A. T.N. 2798.

Tests of 24S-T4 aluminium-alloy specimens subjected to stresses of constant amplitude and to stresses with amplitudes varying according to sinusoidal and exponential functions are reported. The results are analysed by computing the summation of cycle ratios. The values obtained in this analysis were found to be influenced by the shape of the frequency-distribution curve.—(20.2).

An engineering method for estimating notch-size effect in fatigue tests on steel. P. Kuhn and H. F. Hardrath. N.A.C.A. T.N. 2805.

Neuber's proposed method of calculating a practical factor of stress concentration for parts containing notches of arbitrary size depends on the knowledge of a "new material constant" which can be established only indirectly. In this paper, the new constant has been evaluated for a large variety of steels from fatigue tests reported in the literature, attention being confined to stresses near the endurance limit; reasonably satisfactory results were obtained with the assumption that the constant depends only on the tensile strength of the steel.—(20.2.2).

MECHANICAL ENGINEERING

The effect of notches on the strength of aluminium alloys under static tensile loading. J. H. Palm. N.L.L. Report M. 1866.

The true fracture strength in static tensile loading of sharply notched cylindrical test bars of 24ST and 51SW aluminium alloys was investigated. The following factors were varied: length of testbar; size; notch angle; notch depth at constant diameter of notched section. A notch angle of zero degrees with practically infinite sharpness was obtained by precompression. The principle of an optical method is described, which enables to measure the change of diameter of the notched section and to observe the initiation of cracks.—(22.1 × 20.6.2).

METEOROLOGY

Summary of available hail literature and the effect of hail on aircraft in flight. R. K. Souter and J. B. Emerson. N.A.C.A. T.N. 2734.

This paper attempts to co-ordinate the present knowledge of hail with the effect of hail on aircraft in flight and includes (1) a digest of the literature on the physical properties, the occurrence, and the formation of hail; (2) a survey of the hail effect on aircraft in flight from analyses of 57 cases of aeroplanes damaged by hail; (3) a résumé of hail information for the benefit of pilots, forecasters, and ground operational personnel; and (4) an annotated hail bibiliography of 552 articles for use of research personnel.—(23 × 29.1).

RESEARCH

The design and installation of small compressed air turbines for testing powered dynamic models in the Royal Aircraft Establishment seaplane tank. D. I. T. P. Llewelyn-Davies, W. D. Tye and D. C. MacPhail. R. & M. 2620.

The report describes the development of small lightweight air turbines for powering dynamic models in the R.A.E. Seaplane Tank. The units have proved to be rugged and reliable and power/weight ratios of 0·4 lb./b.h.p. have been achieved. The installation of the turbines in dynamic models and the provision of their air supply are also discussed.—(30.1).

An experimental investigation of protection achieved by sweat cooling on porous surfaces adjacent to non-porous surfaces. E. Duncombe. N.A.E., Canada, Report R. 16.

The process of sweat cooling is defined as one in which the coolant is forced from the cold side through pores in the material to be cooled, from which it issues as a protective layer on the hot side. This effect was investigated for a porous bronze cylinder, hot gas being passed through the centre and cooling gas forced radially inwards. The cylinder was continued in both upstream and downstream directions by non-porous bronze extensions. The variation of protection with coolant flow for various temperature differences and positions downstream on the cylinders was measured. A comparison with theoretical predictions was undertaken both on the basis of flat plate laminar boundary layer theory and fully developed turbulent pipe flow. The former yielded a predicted protection that was far too high, but the latter gave results that rapidly approached theoretical predictions as distance downstream increased.—(30.3 × 26).

STRUCTURES

The influence of the method of stringer attachment on the buckling and failure of skin panels with square top-hat stringers. Abstract from the thesis of E. E. Labram. A.R.C. Current Paper 93.

The results of experiments to find the buckling and failing loads of panels with riveted and glued stringers are given, and a comparison between the two methods of attachment is made. In the case of buckling stresses, a comparison is made with theoretical results. It is concluded that the glued panels show noticeably higher buckling and failing stresses, but that failures tend to be more extensive.—(32.2.4).

Some preliminary results from V-g recorders installed in military and civil aircraft. R. Hain Taylor. R. & M. 2610.

During the later half of the 1939-45 war, *V-g* recorder slides were collected from a number of operational and training aircraft types, and about April 1944 the scope was widened to include some commercial transport aircraft. A number of the results has been given limited circulation as Aeronautical Research Council papers, from heavy bombers in October 1943, from fighters in January 1944, and from twin-engined aircraft in April 1944, and a summary of readings from commercial aircraft in 1946; this Report collects these scattered results into one body.—(32.1.2).

Load diffusion at an interspar opening: theoretical methods of analysis compared with strain measurements on a large wing. D. C. Allen. R. & M. 2664.

The diffusion of load from spar flanges into skin and stringers near an opening was investigated experimentally in a large wing structure undergoing strength tests. A comparison of measured strains with those given by theoretical methods shows that in general the flange loads are represented with reasonable accuracy. Any theory, however, in which the chordwise rib at the edge of the opening is ignored gives shear stresses much greater than those measured. Allowance for the bending stiffness of this rib produces values of shear stress comparable with those obtained experimentally.—(32.2.3).

Bending of thin plates with compound curvature. H. G. Lew. N.A.C.A. T.N. 2782.

A method is developed for analysis of deformations of doubly curved thin plates under edge or surface loads for small deflections. The problem is approached from thin-shell theory so that the plate is to form part of a shell of revolution. An analytical solution is presented completely for a plate with arbitrary meridian of small curvature loaded by normal edge loads on one pair of opposite edges and numerical calculations are given for the deflection and moment distribution for a particular meridian curve. The method developed may be applied to other problems of bending of doubly curved thin plates under edge or surface loads but the theory is limited to small deflections of the plate considered.—(32.2.1).

Some dynamic effects of fuel motion in simplified model tip tanks on suddenly excited bending oscillations. K. F. Merten and B. H. Stephenson. N.A.C.A. T.N. 2789.

An exploratory investigation of the dynamic effects of fuel sloshing in tip tanks on wing bending motion was conducted with two simplified model beam-tank systems. Envelope curves to beam-displacement time histories obtained after release from a deflected position are compared and show the effects of variation in tank fullness, fluid density, fluid viscosity, and tank shape. Some variations of fluid weight effective from cycle to cycle are also presented.—(32.1.2).

APPOINTMENTS

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APPLY TO CHIEF DESIGNER

An experimental investigation of the behavior of 24S-T4 aluminum alloy subjected to repeated stresses of constant and varying amplitudes. H. F. Hardrath and E. C. Utley, Jr. N.A.C.A. T.N. 2798.

Tests of 24S-T4 aluminium-alloy specimens subjected to stresses of constant amplitude and to stresses with amplitudes varying according to sinusoidal and exponential functions are reported. The results are analysed by computing the summation of cycle ratios. The values obtained in this analysis were found to be influenced by the shape of the frequency-distribution curve.—(20.2).

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MECHANICAL ENGINEERING

The effect of notches on the strength of aluminium alloys under static tensile loading. J. H. Palm. N.L.L. Report M. 1866.

The true fracture strength in static tensile loading of sharply notched cylindrical test bars of 24ST and 51SW aluminium alloys was investigated. The following factors were varied: length of testbar; size; notch angle; notch depth at constant diameter of notched section. A notch angle of zero degrees with practically infinite sharpness was obtained by precompression. The principle of an optical method is described, which enables to measure the change of diameter of the notched section and to observe the initiation of cracks.—(22.1 × 20.6.2).

METEOROLOGY

Summary of available hail literature and the effect of hail on aircraft in flight. R. K. Souter and J. B. Emerson. N.A.C.A. T.N. 2734.

This paper attempts to co-ordinate the present knowledge of hail with the effect of hail on aircraft in flight and includes (1) a digest of the literature on the physical properties, the occurrence, and the formation of hail; (2) a survey of the hail effect on aircraft in flight from analyses of 57 cases of aeroplanes damaged by hail; (3) a résumé of hail information for the benefit of pilots, forecasters, and ground operational personnel; and (4) an annotated hail bibiliography of 552 articles for use of research personnel.—(23 × 29.1).

RESEARCH

The design and installation of small compressed air turbines for testing powered dynamic models in the Royal Aircraft Establishment seaplane tank. D. I. T. P. Llewelyn-Davies, W. D. Tye and D. C. MacPhail. R. & M. 2620.

The report describes the development of small lightweight air turbines for powering dynamic models in the R.A.E. Seaplane Tank. The units have proved to be rugged and reliable and power/weight ratios of 0·4 lb./b.h.p. have been achieved. The installation of the turbines in dynamic models and the provision of their air supply are also discussed.—(30.1).

An experimental investigation of protection achieved by sweat cooling on porous surfaces adjacent to non-porous surfaces. E. Duncombe. N.A.E., Canada, Report R. 16.

The process of sweat cooling is defined as one in which the coolant is forced from the cold side through pores in the material to be cooled, from which it issues as a protective layer on the hot side. This effect was investigated for a porous bronze cylinder, hot gas being passed through the centre and cooling gas forced radially inwards. The cylinder was continued in both upstream and downstream directions by non-porous bronze extensions. The variation of protection with coolant flow for various temperature differences and positions downstream on the cylinders was measured. A comparison with theoretical predictions was undertaken both on the basis of flat plate laminar boundary layer theory and fully developed turbulent pipe flow. The former yielded a predicted protection that was far too high, but the latter gave results that rapidly approached theoretical predictions as distance downstream increased.—(30.3 × 26).

STRUCTURES

The influence of the method of stringer attachment on the buckling and failure of skin panels with square top-hat stringers. Abstract from the thesis of E. E. Labram. A.R.C. Current Paper 93.

The results of experiments to find the buckling and failing loads of panels with riveted and glued stringers are given, and a comparison between the two methods of attachment is made. In the case of buckling stresses, a comparison is made with theoretical results. It is concluded that the glued panels show noticeably higher buckling and failing stresses, but that failures tend to be more extensive.—(32.2.4).

Some preliminary results from V-g recorders installed in military and civil aircraft. R. Hain Taylor. R. & M. 2610.

During the later half of the 1939-45 war, *V-g* recorder slides were collected from a number of operational and training aircraft types, and about April 1944 the scope was widened to include some commercial transport aircraft. A number of the results has been given limited circulation as Aeronautical Research Council papers, from heavy bombers in October 1943, from fighters in January 1944, and from twin-engined aircraft in April 1944, and a summary of readings from commercial aircraft in 1946; this Report collects these scattered results into one body.—(32.1.2).

Load diffusion at an interspar opening: theoretical methods of analysis compared with strain measurements on a large wing. D. C. Allen. R. & M. 2664.

The diffusion of load from spar flanges into skin and stringers near an opening was investigated experimentally in a large wing structure undergoing strength tests. A comparison of measured strains with those given by theoretical methods shows that in general the flange loads are represented with reasonable accuracy. Any theory, however, in which the chordwise rib at the edge of the opening is ignored gives shear stresses much greater than those measured. Allowance for the bending stiffness of this rib produces values of shear stress comparable with those obtained experimentally.—(32.2.3).

Bending of thin plates with compound curvature. H. G. Lew. N.A.C.A. T.N. 2782.

A method is developed for analysis of deformations of doubly curved thin plates under edge or surface loads for small deflections. The problem is approached from thin-shell theory so that the plate is to form part of a shell of revolution. An analytical solution is presented completely for a plate with arbitrary meridian of small curvature loaded by normal edge loads on one pair of opposite edges and numerical calculations are given for the deflection and moment distribution for a particular meridian curve. The method developed may be applied to other problems of bending of doubly curved thin plates under edge or surface loads but the theory is limited to small deflections of the plate considered.—(32.2.1).

Some dynamic effects of fuel motion in simplified model tip tanks on suddenly excited bending oscillations. K. F. Merten and B. H. Stephenson. N.A.C.A. T.N. 2789.

An exploratory investigation of the dynamic effects of fuel sloshing in tip tanks on wing bending motion was conducted with two simplified model beam-tank systems. Envelope curves to beam-displacement time histories obtained after release from a deflected position are compared and show the effects of variation in tank fullness, fluid density, fluid viscosity, and tank shape. Some variations of fluid weight effective from cycle to cycle are also presented.—(32.1.2).

APPOINTMENTS

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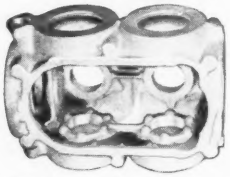

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